Higgs Effective Field Theories results in the ATLAS experiment

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https://indico.ijclab.in2p3.fr/event/7779/
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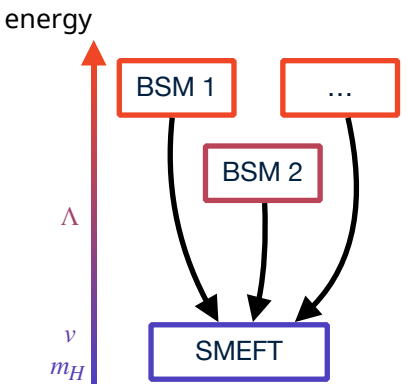
Introduction

- **Effective field theories (EFTs)** can capture effects of **heavy BSM states** as **perturbation around the Standard Model**
  - different approaches possible: SM ⊂ SMEFT ⊂ HEFT (see arXiv:1706.08945 for a review)

- **Standard Model Effective Field Theory (SMEFT)**
  - $\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum \frac{c_i}{\Lambda^2} \mathcal{O}_i^{d=6} + \ldots$ *
    - expand SM with additional $SU(3)_C \times SU(2)_L \times U(1)_Y$ invariant interactions
    - expansion parameter Λ interpreted as mass scale of new physics
  - different flavor symmetry assumptions possible: e.g. $U(3)^5$, $U(2)_q \times U(2)_u \times U(3)_d \times U(3)_l \times U(3)_e$
  - Wilson coefficients (free parameters) c_i are correlated



BSM models could leave imprints at accessible energy scales, measured via Wilson coefficients

- **Higgs Effective Field Theory (HEFT)**
  - non-linearly realized electroweak symmetry with Higgs boson + independent Goldstone bosons
  - more general than SMEFT, no correlations between free parameters

* odd-dimensional operators vanish with lepton and baryon number conservation

Overview of recent ATLAS Higgs EFT results

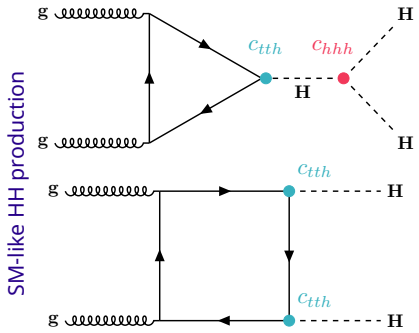
- **HEFT**
  - **Di-Higgs $b\bar{b}\tau\tau$ + $b\bar{b}\gamma\gamma$ HEFT interpretation** (March 2022, ATL-PHYS-PUB-2022-019)

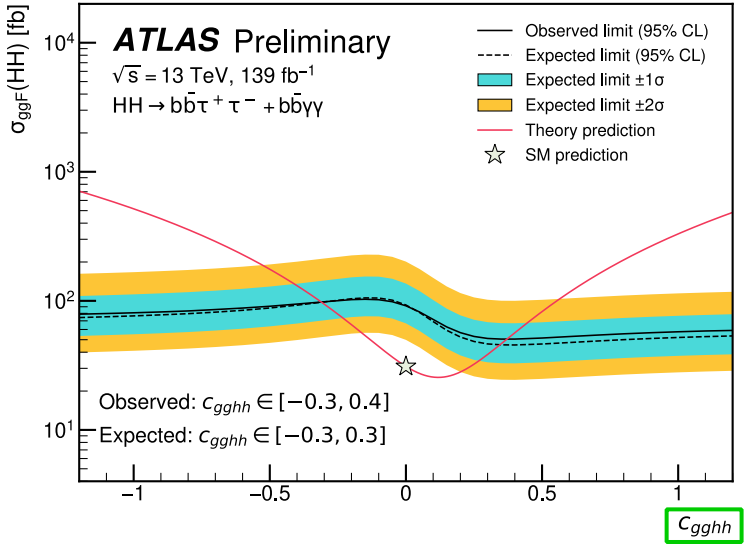
- **SMEFT**
  - $H \to \gamma\gamma$ **differential cross-section** (Feb 2022, JHEP 08 (2022) 027)
  - $H \to \gamma\gamma$ **STXS** with EFT interpretation (July 2022, HIGG-2020-16)
  - **STXS Higgs combination** with EFT interpretation (Nov 2021, ATLAS-CONF-2021-053)
  - **Higgs + EW + precision observables** SMEFT global fit (July 2022, ATL-PHYS-PUB-2022-037)

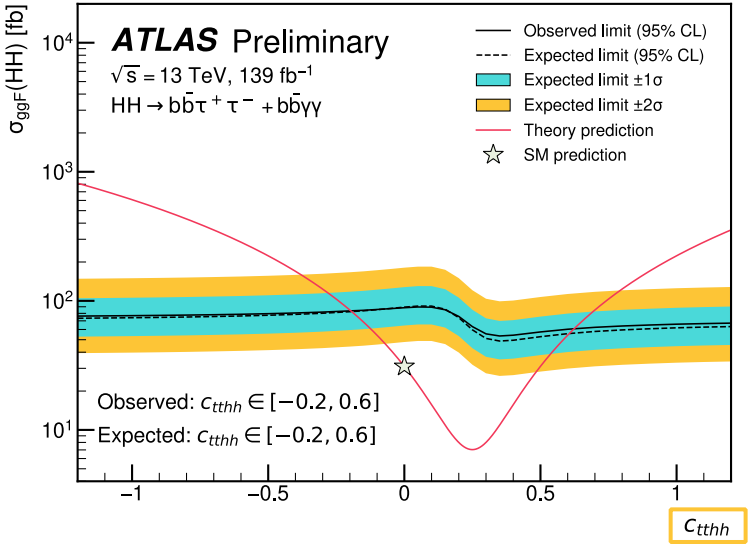
combinations with increasing number of input analyses

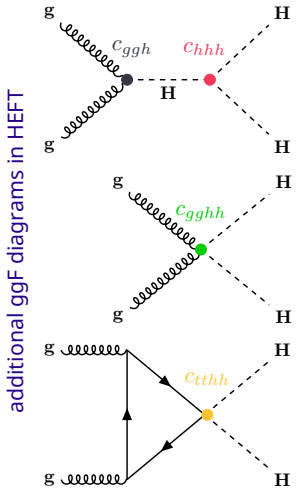
Di-Higgs $b\bar{b}\tau\tau$ + $b\bar{b}\gamma\gamma$ HEFT interpretation

- **HEFT interpretation of di-Higgs* in $b\bar{b}\tau\tau$ and $b\bar{b}\gamma\gamma$ final states + combination**
  - $b\bar{b}\tau\tau$: template fit to NN and BDT, $b\bar{b}\gamma\gamma$: unbinned fit to $m_{\gamma\gamma}$ across multiple categories
  - m_{HH} based reweighting of SM HH sample, limits also set on 7 HEFT benchmark models (backup)
  - limits on HEFT Wilson coefficients c_{gghh} and c_{tthh} from $b\bar{b}\tau\tau + b\bar{b}\gamma\gamma$ combination
    - ATLAS-CONF-2021-052: c_{hhh} obs. (exp.) limit : $-1.0 < c_{hhh} < 6.6$ $(-1.2 < c_{hhh} < 7.2)$









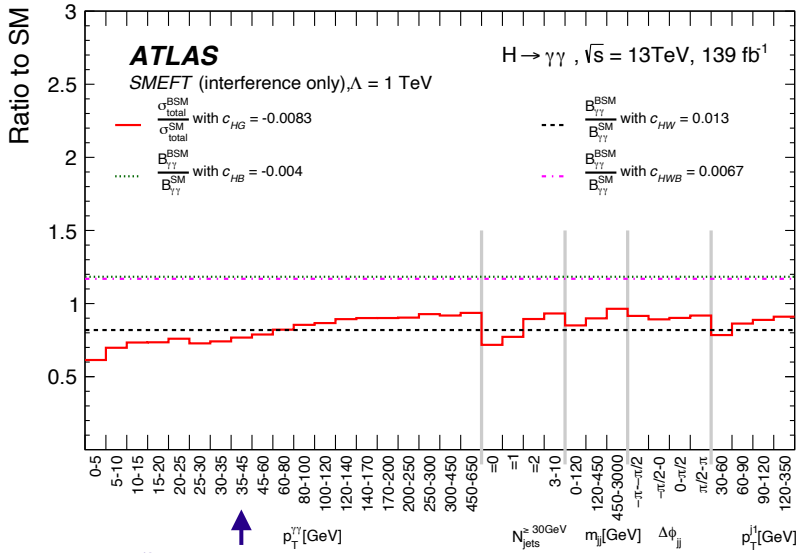
* see arXiv:1806.05162 for details about the model

JHEP 08 (2022) 027

$H \to \gamma\gamma$ differential cross-section

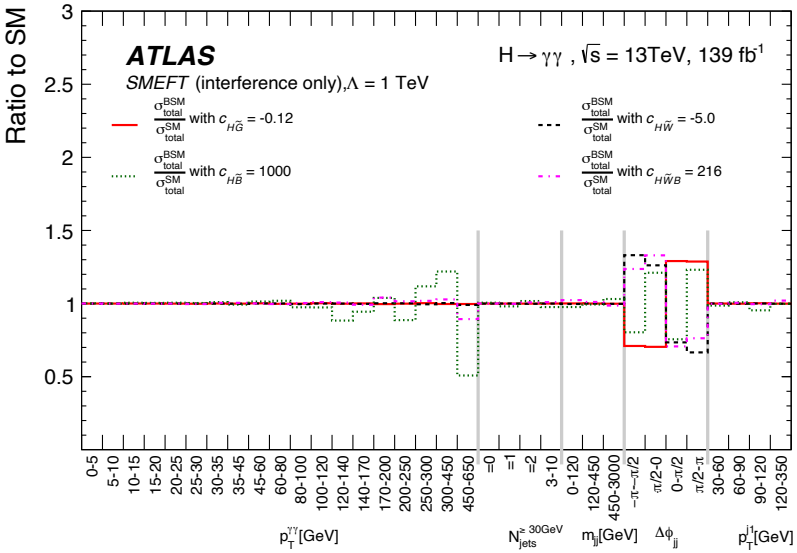
- **SMEFT interpretation of $H \to \gamma\gamma$ differential cross-section measurement**
  - simultaneous fit to five measured differential distributions: $p_T^{\gamma\gamma}, N_{jets}, m_{jj}, \Delta\Phi_{jj}, p_T^{j1}$ (covariance matrix via bootstrapping)
  - 8 Wilson coefficients measured (one at a time) in Warsaw basis
    - c_{HG}, $c_{H\tilde{G}}$ scale ggF, c_{HW}, c_{HB}, c_{HWB} (+ CP-odd versions) affect mostly $H \to \gamma\gamma$ rate and VBF, VH

CP-even operator effects



$p_T^{\gamma\gamma}$ dependent effect of of c_{HG}

CP-odd operator effects

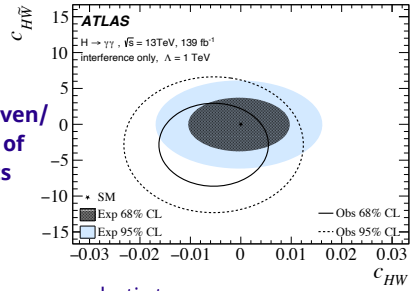


sensitivity to CP-odd operators via $\Delta\phi_{jj}$

$H \to \gamma\gamma$ differential cross-section

- **Individual constraints** for **one Wilson coefficient at a time** as well as **2D limits**
  - CP-even coefficients: similar results when including quadratic terms
  - CP-odd coefficients: significant differences with quadratic terms

limits for CP-even/ CP-odd pair of coefficients



interference terms

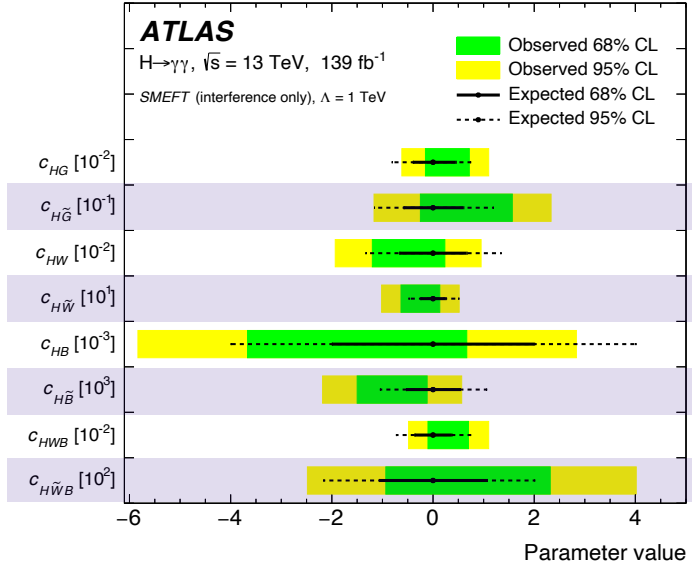
$$\sigma = \left|\mathcal{A}_{SM}\right|^2 + \sum_i \frac{c_i}{\Lambda^2} 2Re\left(\mathcal{A}^*_{SM}\mathcal{A}_{i,d6}\right)$$

interference terms quadratic terms

$$\left|\mathcal{A}_{SM}\right|^2 + \sum_i \frac{c_i}{\Lambda^2} 2Re\left(\mathcal{A}^*_{SM}\mathcal{A}_{i,d6}\right) + \left|\sum_i \frac{c_i}{\Lambda^2}\mathcal{A}_{i,d6}\right|^2$$

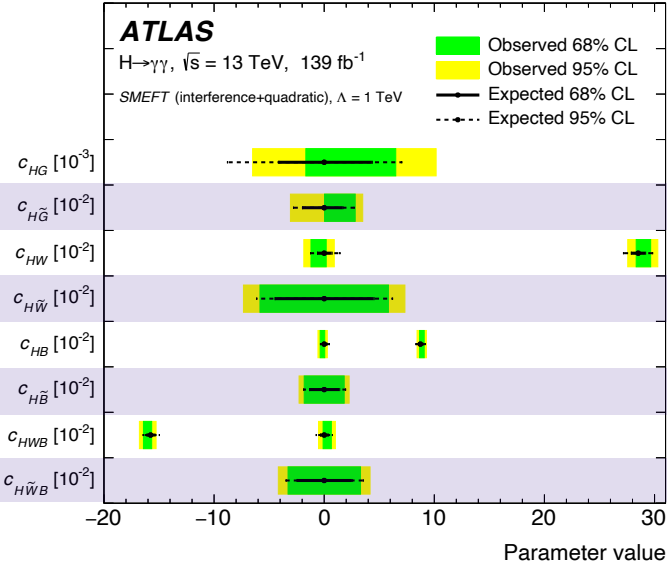
c_{HB}: $[-5.8, 2.8] \times 10^{-3}$ probes energy scales up to $\Lambda = 15$ TeV

very limited sensitivity without quadratic terms

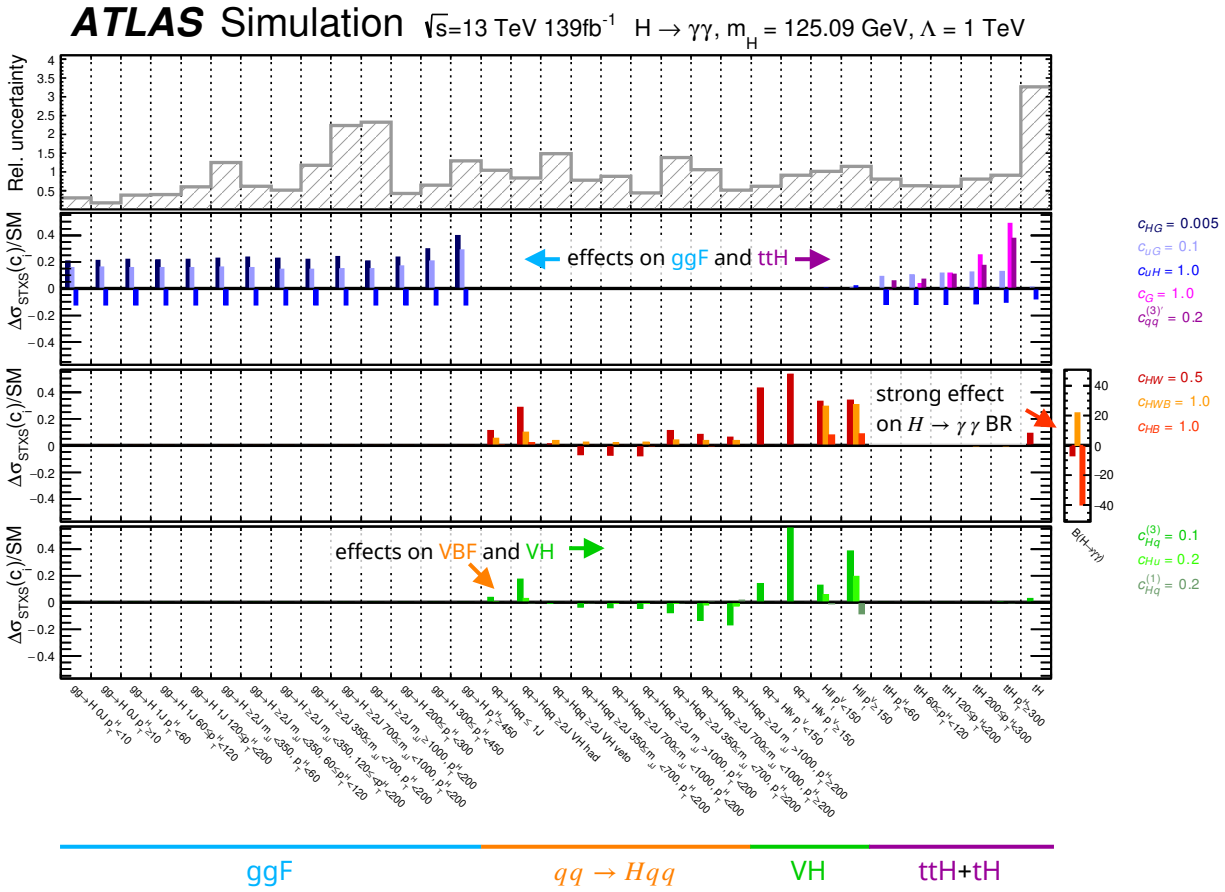


CP-even

CP-odd



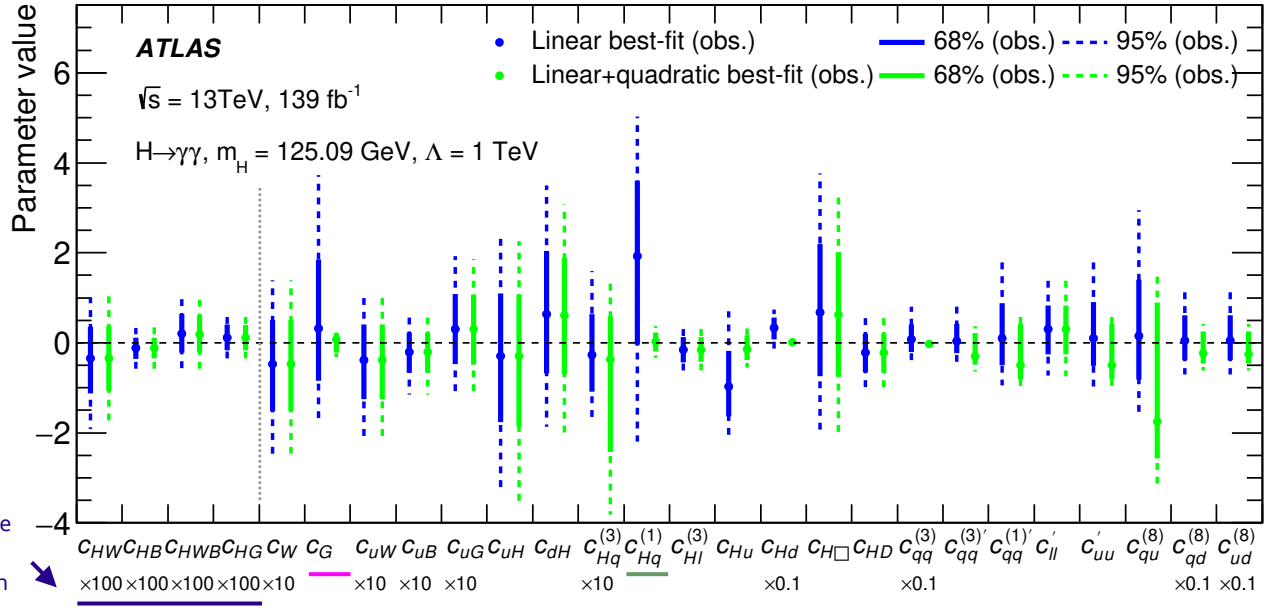
$H \to \gamma\gamma$ STXS interpretation



- **SMEFT interpretation of 33-bin STXS measurement**
  - targeting different production modes and binned in $p_T^H, m_{jj}, N_{jets}, p_T^V$
  - fitting STXS bins with Higgs processes parameterized by Wilson coefficients
  - affected by 34 Wilson coefficients in Warsaw basis
- **Left:** relative impact per STXS bin of most relevant SMEFT operators

$H \to \gamma\gamma$ STXS interpretation

- **SMEFT measurement results** (one Wilson coefficient at a time)
  - difference between linear and linear+quadratic parameterization indicate potential impact of higher-order terms
    - especially for parameters sensitive to high p_T^H in ttH / ggF (e.g. c_G) and high p_T^V in VH (e.g. $c_{Hq}^{(1)}$)
  - simultaneous fit of 12 linear combinations of Wilson coefficients also performed (backup)



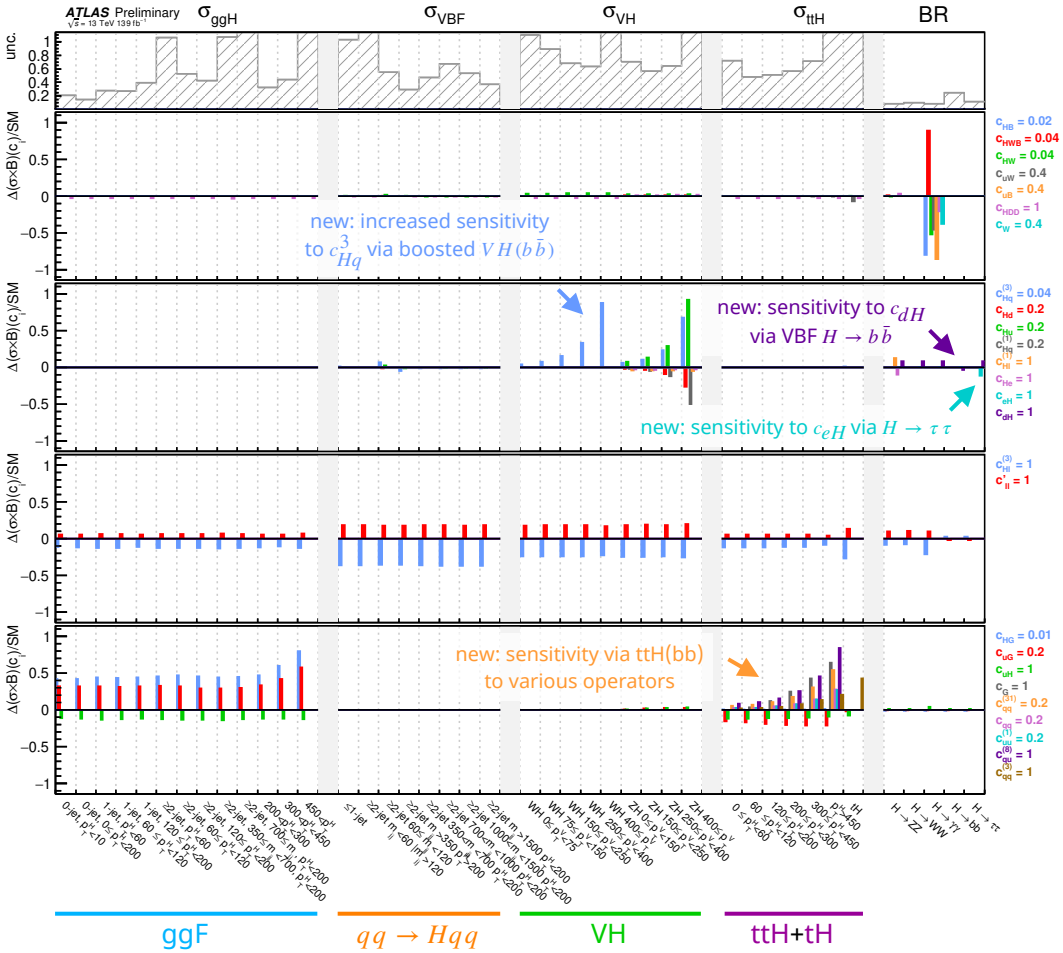
sensitivity comparable to differential cross-section interpretation

more combination results:
Paolo Francavilla's talk

Higgs combination STXS interpretation

ATLAS-CONF-2021-053

- **SMEFT interpretation of statistical combination of many Higgs analyses**
  - signal strength per STXS bin parameterized as function of Wilson coefficients



analyses used in EFT interpretation

*: new or updated wrt. previous combination (ATLAS-CONF-2020-053)

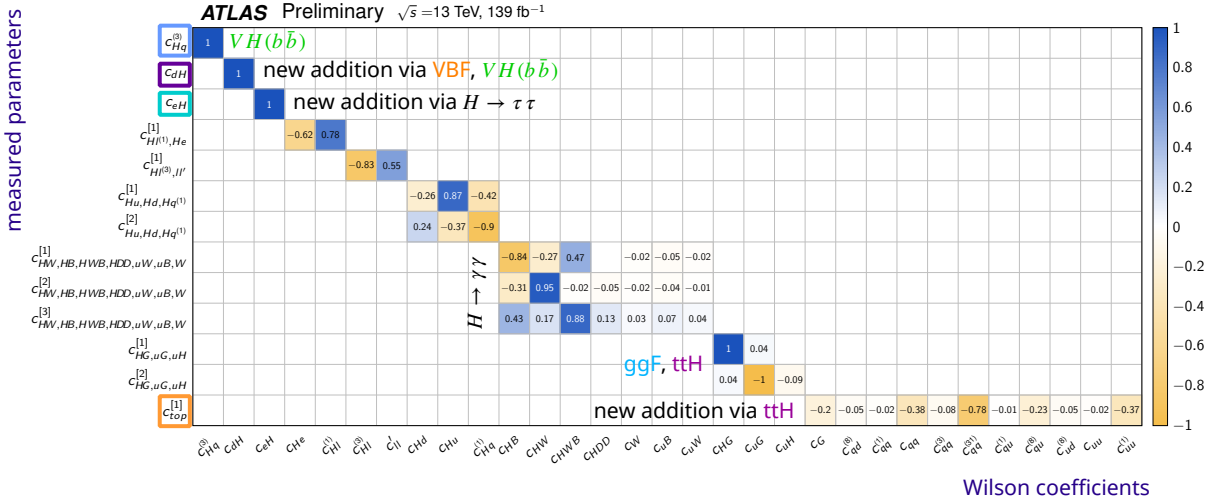
Decay channel	Production modes	Reference
H→γγ	ggF, VBF, VH, ttH/tH	ATLAS-CONF-2020-026
H→ZZ*→4l	ggF, VBF, VH, ttH	Eur. Phys. J. C 80 (2020) 957
H→WW*	ggF*, VBF*	ATLAS-CONF-2021-014
H→ττ	ggF*, VBF*, VH*, ttH*	ATLAS-CONF-2021-044
H→bb̄	VBF*, VH*, ttH*	VBF, VH: 1, 2, 3, ttH

Higgs combination STXS interpretation

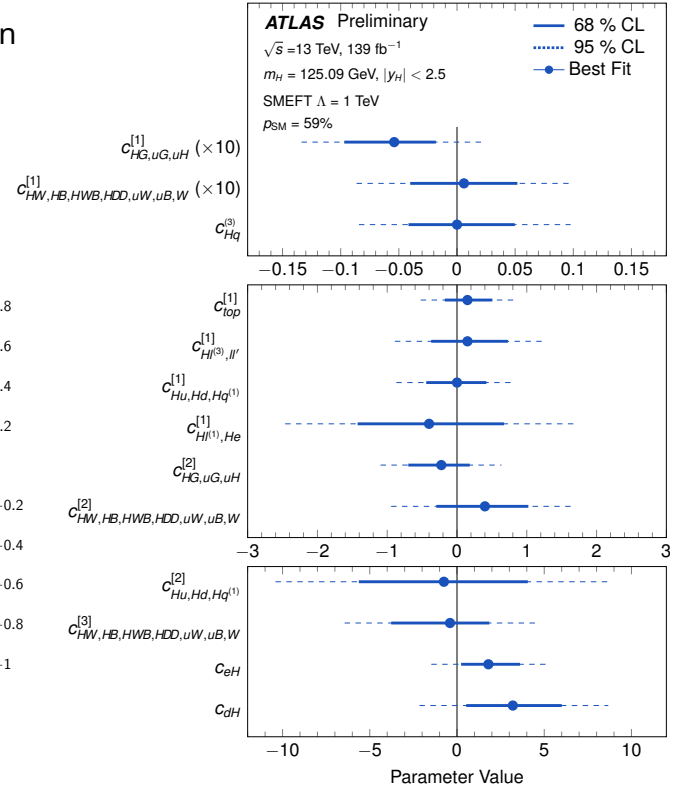
- **Principal component analysis** to identify **linear combinations of Wilson coefficients** to which analysis is sensitive
  - 3 coefficients and 10 linear combinations measured simultaneously ($p_{SM} = 59\,\%$)
  - reduced correlations and up to 70% better constraints than previous iteration

projection from Warsaw basis to fit basis

highlighting examples of input analyses providing sensitivity



results (using linear model)



Global SMEFT fit: Higgs + EW + EWPO

- **First ATLAS global EFT interpretation**
  - ATLAS Higgs STXS measurement (ATLAS-CONF-2021-053)
  - ATLAS differential cross-section measurements of weak boson production (ATL-PHYS-PUB-2021-022)
    - unfolded fiducial cross-sections: $WW\,(p_T^{l1})$, $WZ\,(m_T^{WZ})$, $4\ell\,(m_{Z2})$, VBF $Z\,(\Delta\Phi_{jj})$
  - LEP + SLC electroweak precision observables (EWPO) (Phys. Rept. 427 (2006) 257), 8 observables included

LEP/SLC EWPO:

$$\Gamma_Z, \sigma^0_{had}, R^0_\ell, A^{0,l}_{FB}$$
$$R^0_b, R^0_c, A^{0,b}_{FB}, A^{0,c}_{FB}$$

with

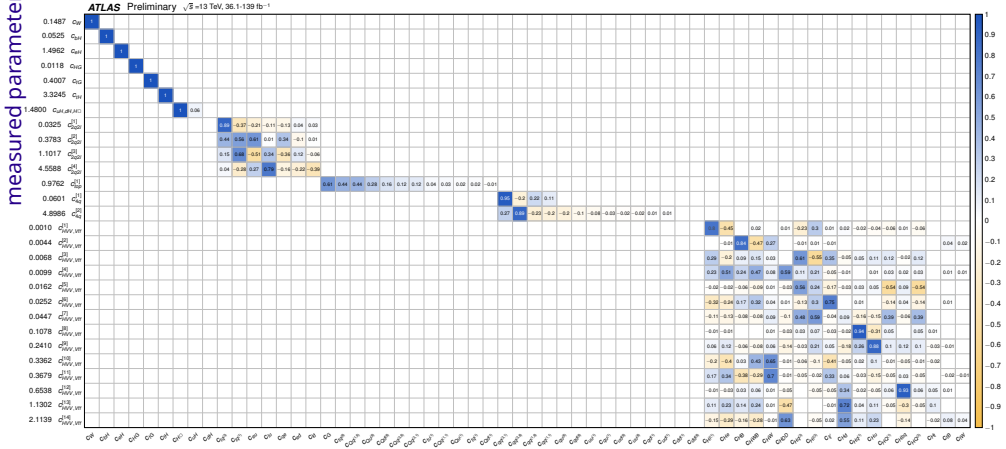
$$\sigma^0_{had} = \frac{12\pi}{m_Z^2}\frac{\Gamma_{ee}\Gamma_{had}}{\Gamma_Z^2}$$

$$R^0_\ell = \frac{\Gamma_{had}}{\Gamma_{\ell\ell}},\ R^0_q = \frac{\Gamma_{qq}}{\Gamma_{had}}$$

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

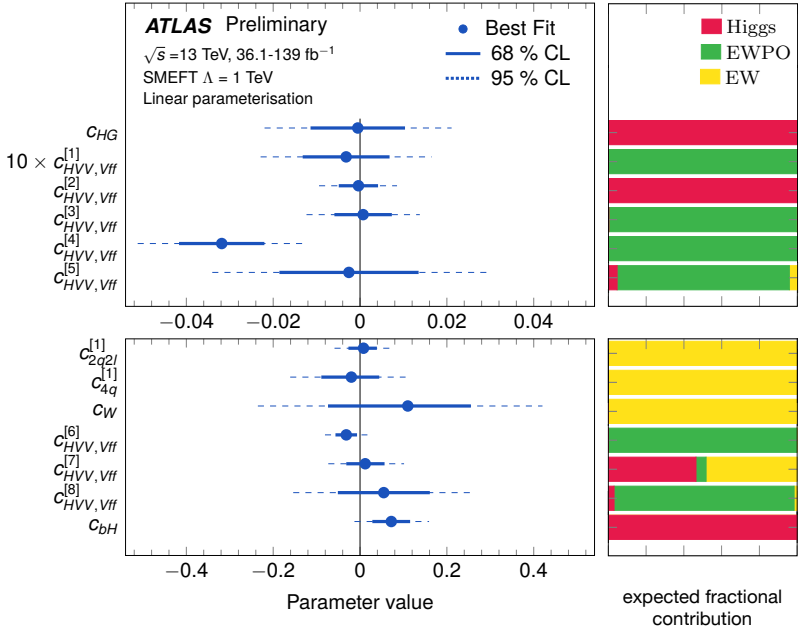
- **Measurement setup**
  - overlap removed between ATLAS Higgs and EW inputs
  - assuming flavor symmetry between first two quark generations and all three lepton generations
  - PCA to identify 28 linear combinations of c_i
  - combination also with only ATLAS inputs (backup)

projection from Warsaw basis to fit basis



Global SMEFT fit: Higgs + EW + EWPO

- **Measurement performed for 6 Wilson coefficients + 22 linear combinations** (linear parameterization)
  - fractional contribution of measurements with uncertainty σ_i calculated as $\sigma_i^{-2}/\Sigma_j\sigma_j^{-2}$
  - simplified multivariate Gaussian likelihood model available, which reproduces results well
  - largest deviation from SM: $c^{[4]}_{HVV,VFF}$ from known $A^{0,b}_{FB}, A^{0,c}_{FB}$ discrepancies



largest contributions for most sensitive parameters:

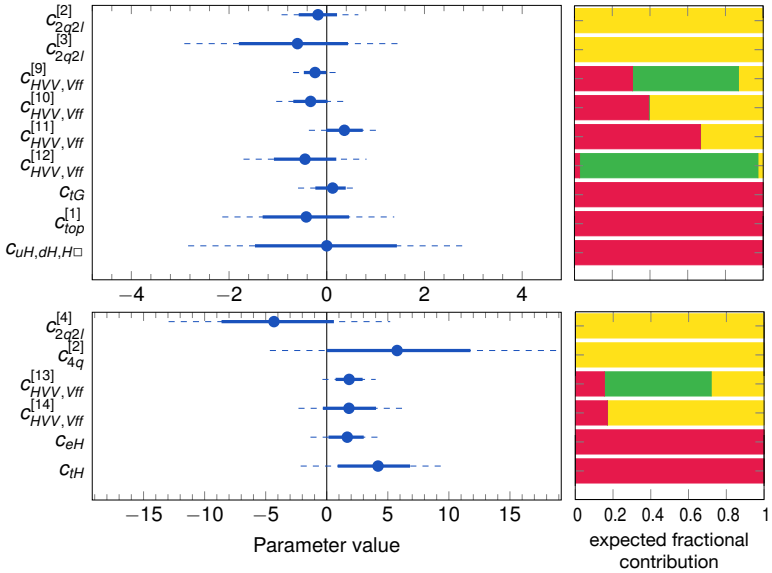
ggH

σ^0_{had}

$H \to \gamma\gamma$

F/B asymmetries

F/B asymmetries



Summary

- **Growing number of Higgs EFT interpretations** performed by ATLAS
  - examples shown in both HEFT and SMEFT frameworks
  - results consistent with the Standard Model observed so far

- **Combinations of measurements** allow probing increasingly large number of operators simultaneously
  - rotations performed from Warsaw basis to linear combinations of operators with sensitivity

- **First global ATLAS EFT interpretation** of ATLAS Higgs + EW results + precision observables
  - includes simultaneous measurement of 28 linear combinations of Wilson coefficients

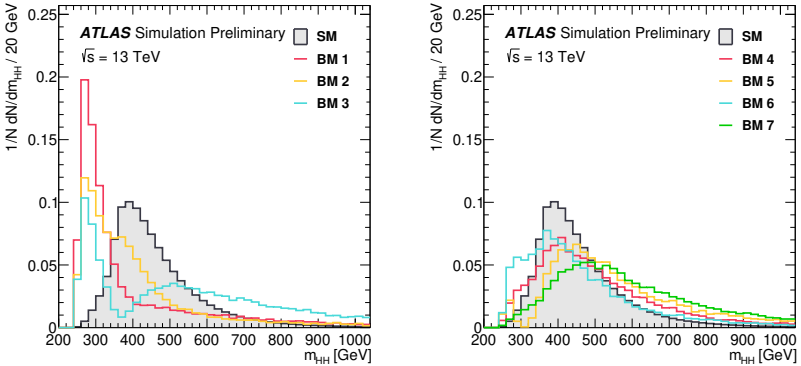
Backup

Di-Higgs $b\bar{b}\tau\tau$ + $b\bar{b}\gamma\gamma$ HEFT interpretation

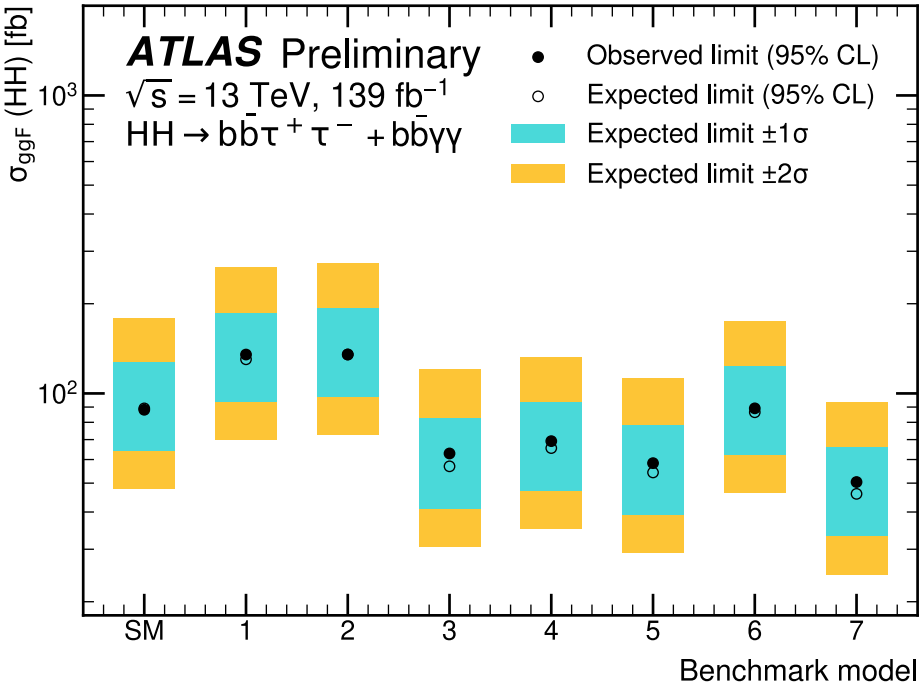
- Definition and results for **seven benchmark models**

Benchmark model	c_{hhh}	c_{tth}	c_{ggh}	c_{gghh}	c_{tthh}
SM	1	1	0	0	0
BM 1	3.94	0.94	1/2	1/3	−1/3
BM 2	6.84	0.61	0.0	−1/3	1/3
BM 3	2.21	1.05	1/2	1/2	−1/3
BM 4	2.79	0.61	−1/2	1/6	1/3
BM 5	3.95	1.17	1/6	−1/2	−1/3
BM 6	5.68	0.83	−1/2	1/3	1/3
BM 7	−0.10	0.94	1/6	−1/6	1

particle-level distributions for benchmark models



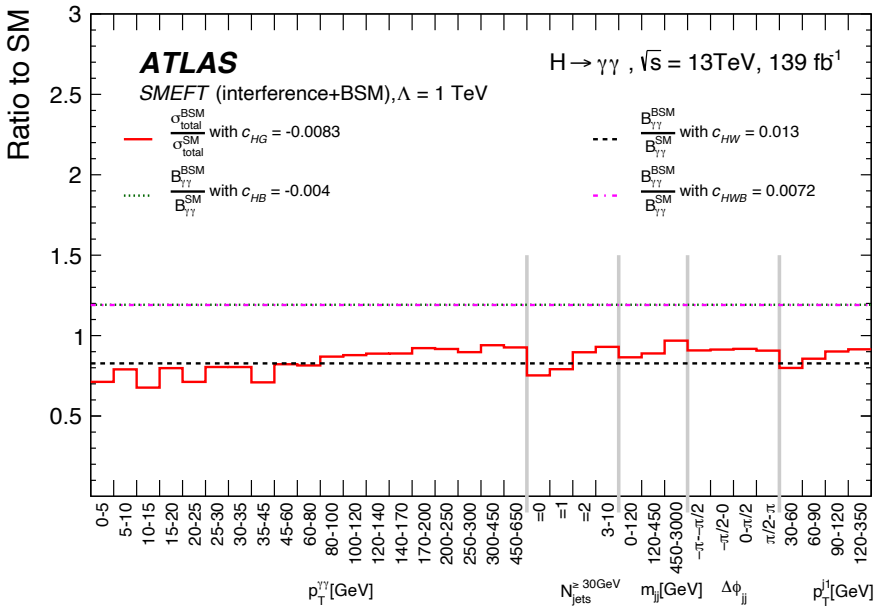
expected limits assume no ggF HH production



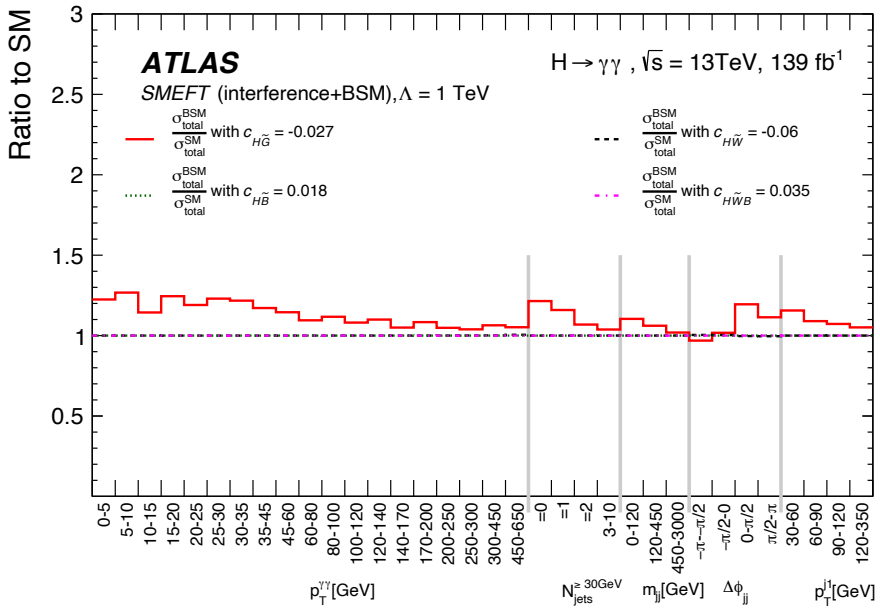
$H \to \gamma\gamma$ differential cross-section

- Results for **Wilson coefficient measurements**
- Effects of operators when considering **linear and quadratic terms**

Coefficient	95% CL, interference-only terms	95% CL, interference and quadratic terms
c_{HG}	$[-6.1, 11.0] \times 10^{-3}$	$[-6.5, 10.2] \times 10^{-3}$
$c_{H\widetilde{G}}$	$[-0.12, 0.23]$	$[-3.1, 3.5] \times 10^{-2}$
c_{HW}	$[-1.9, 0.9] \times 10^{-2}$	$[-1.8, 1.0] \times 10^{-2} \cup [0.28, 0.30]$
$c_{H\widetilde{W}}$	$[-10.2, 5.2]$	$[-7.3, 7.3] \times 10^{-2}$
c_{HB}	$[-5.8, 2.8] \times 10^{-3}$	$[-5.5, 3.0] \times 10^{-3} \cup [8.4, 9.3] \times 10^{-2}$
$c_{H\widetilde{B}}$	$[-21.8, 5.7] \times 10^{2}$	$[-2.3, 2.3] \times 10^{-2}$
c_{HWB}	$[-5.2, 10.7] \times 10^{-3}$	$[-0.17, -0.15] \cup [-5.5, 9.8] \times 10^{-3}$
$c_{H\widetilde{W}B}$	$[-2.5, 4.0] \times 10^{2}$	$[-4.0, 4.0] \times 10^{-2}$



CP-even



CP-odd

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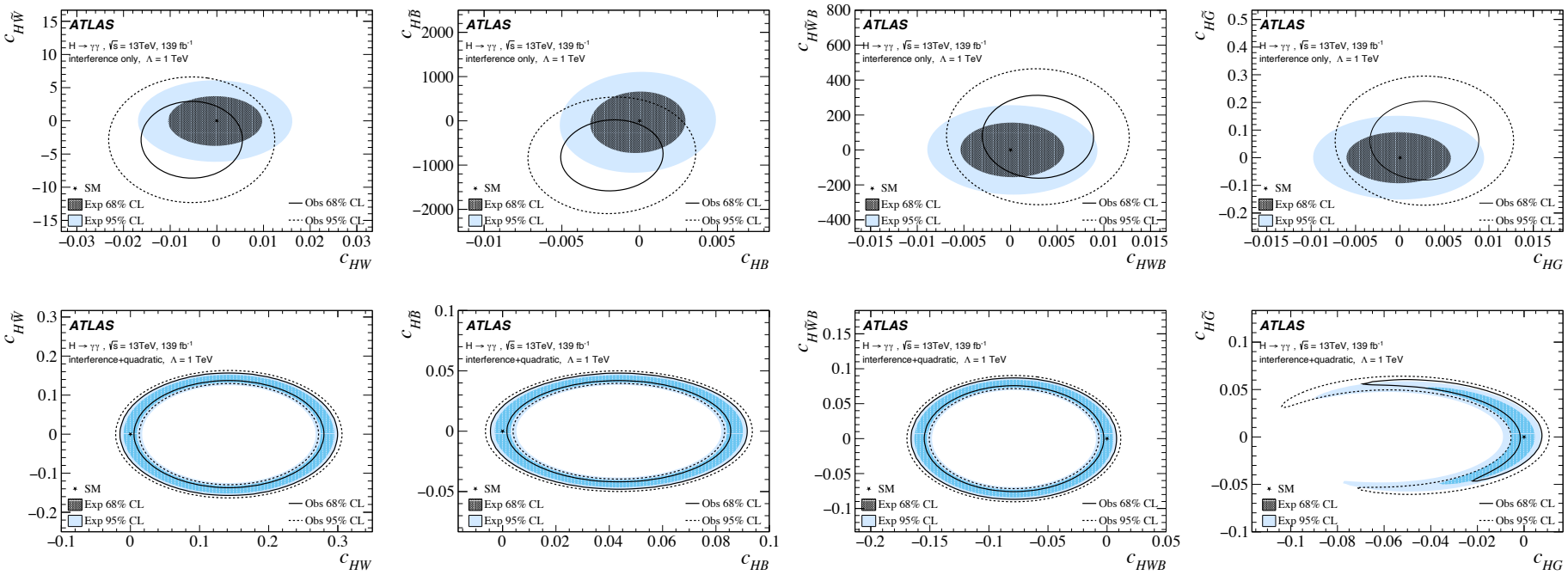
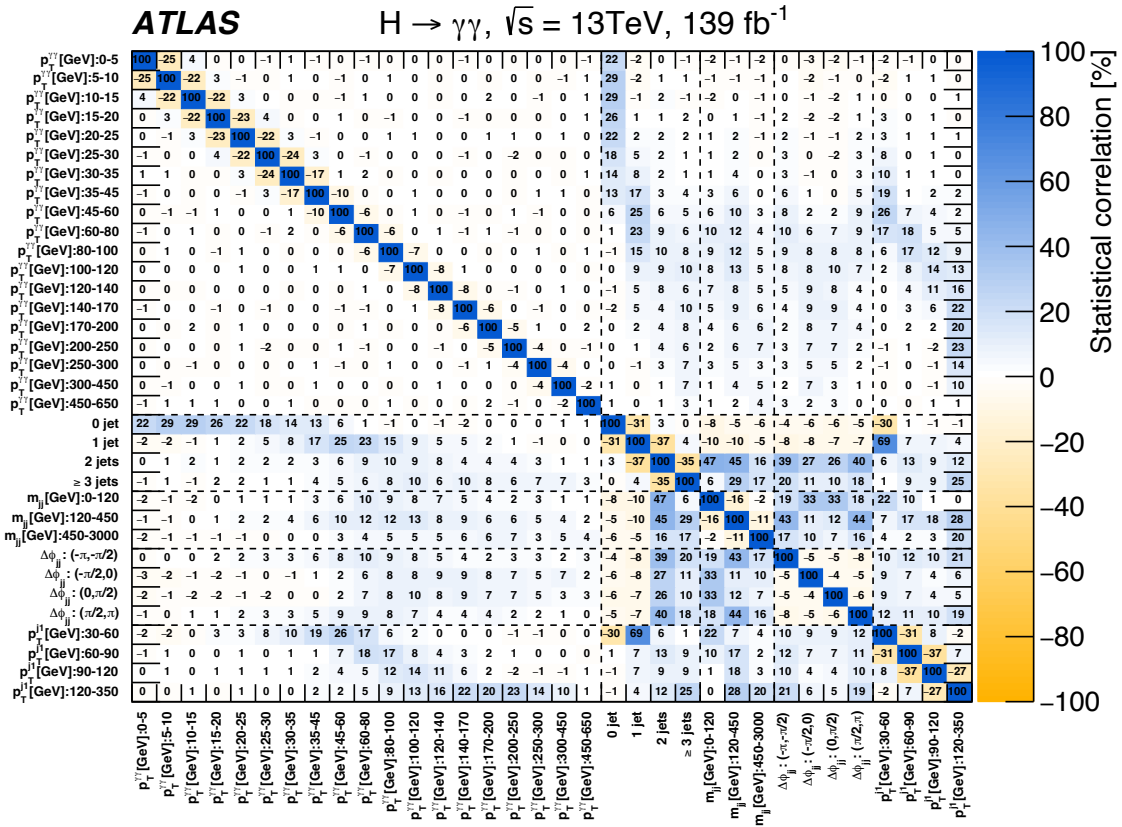
$H \to \gamma\gamma$ differential cross-section

- 68% and 95% confidence level limits for **combinations of two Wilson coefficients**



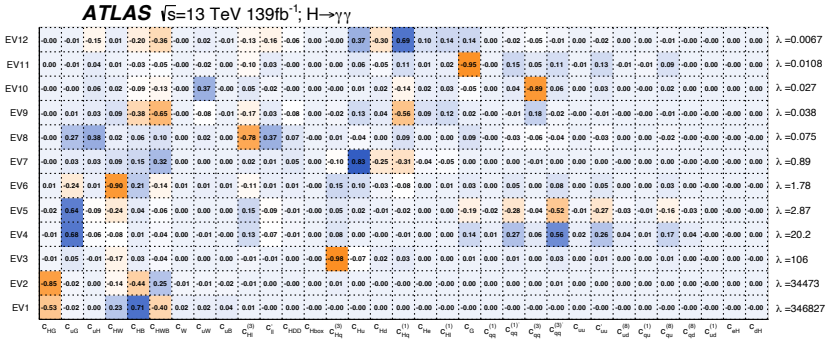
$H \to \gamma\gamma$ differential cross-section

- **Statistical correlations** obtained via bootstrapping

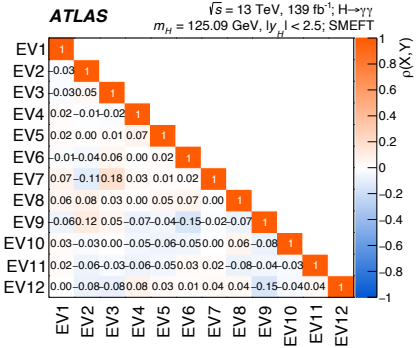


$H \to \gamma\gamma$ STXS interpretation

- **Simultaneous** measurement of **12 linear combinations of Wilson coefficients**
  - identified via PCA (linear model + Gaussian approximation)

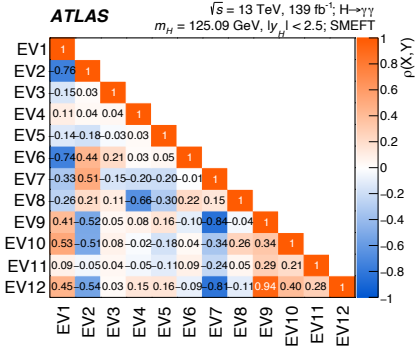


linear parametrization

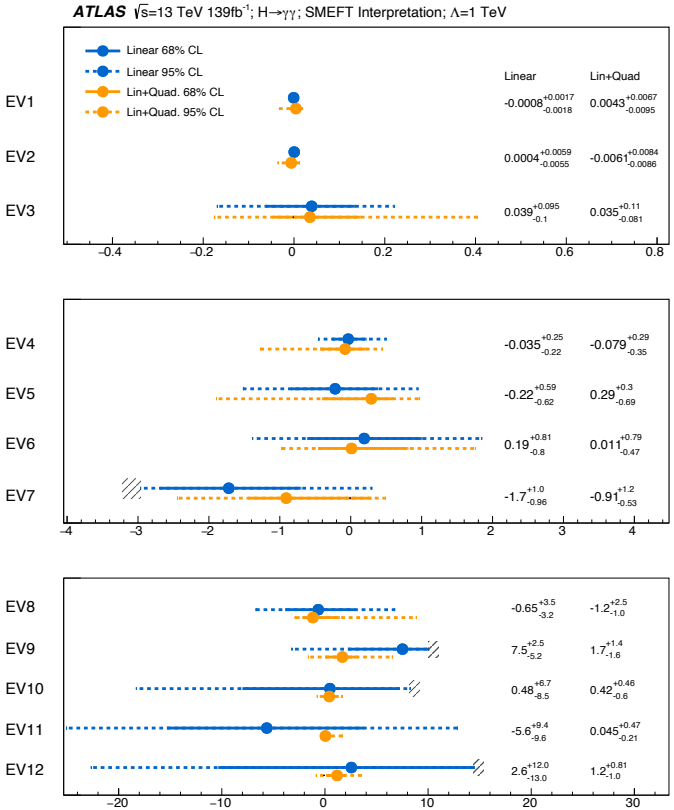


non-zero off-diagonal values due to difference between observed/expected data and Gaussian approximation

linear + quadratic parametrization



non-zero off-diagonal values due to quadratic terms not being considered in PCA

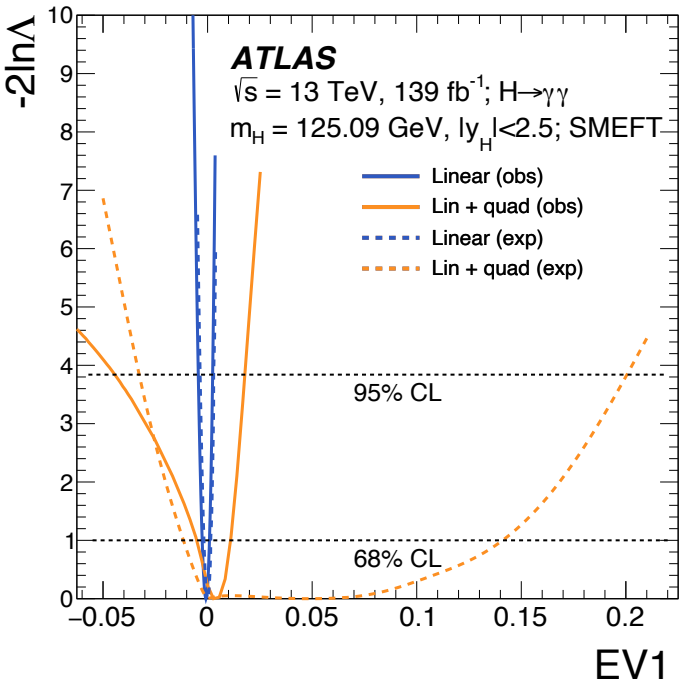


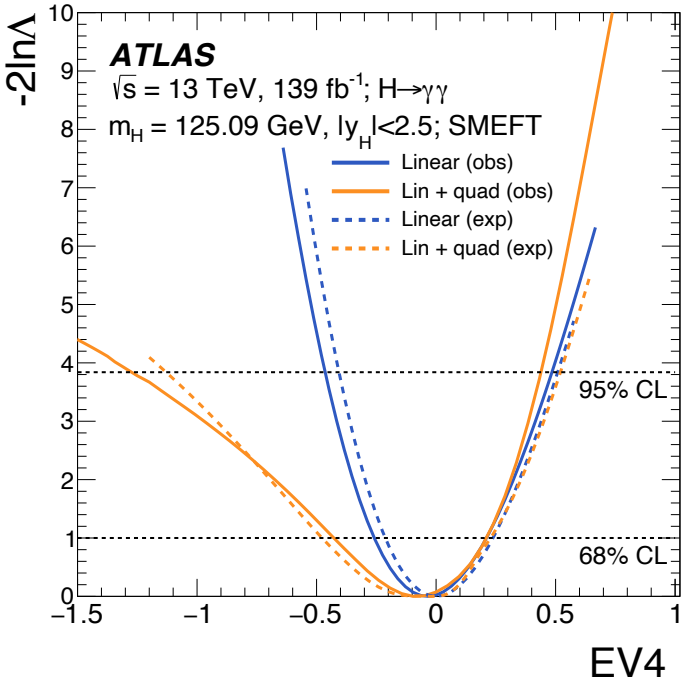
EVs sensitive to:

- total event rates
- difference between ggF and other production modes
- high p_T^V in VH
- high p_T ttH
- high p_T ttH
- VBF rate
- high p_T^V in VH
- difference between ggF and other production modes

$H \to \gamma\gamma$ STXS interpretation

- Profile likelihood **scans over individual EVs**
  - two degenerate minima for EV1, partly lifted for observed data due to small differences to SM expectation





$H \to \gamma\gamma$ STXS interpretation

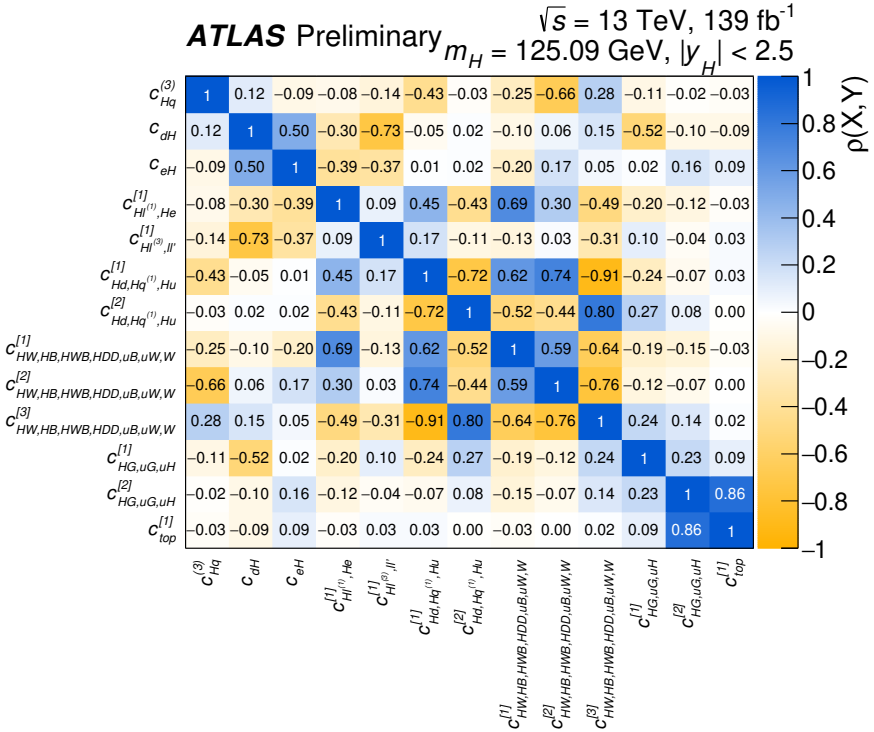
- **Full set of results for Wilson coefficients** within $|c_i| \leq 20$ validity range

Parameter	Observed						Expected			
	linear			linear+quadratic			linear		linear+quadratic	
	Value	Uncertainty		Value	Uncertainty		Uncertainty		Uncertainty	
		68% CL	95% CL		68% CL	95% CL	68% CL	95% CL	68% CL	95% CL
c_{HW}	−0.0035	$^{+0.0071}_{-0.0077}$	$^{+0.014}_{-0.016}$	−0.0034	$^{+0.0071}_{-0.0073}$	$^{+0.014}_{-0.014}$	$^{+0.0070}_{-0.0075}$	$^{+0.013}_{-0.015}$	$^{+0.0072}_{-0.0072}$	$^{+0.014}_{-0.014}$
c_{HB}	−0.0011	$^{+0.0023}_{-0.0025}$	$^{+0.0044}_{-0.0050}$	−0.0011	$^{+0.0023}_{-0.0023}$	$^{+0.0046}_{-0.0046}$	$^{+0.0022}_{-0.0024}$	$^{+0.0043}_{-0.0049}$	$^{+0.0023}_{-0.0023}$	$^{+0.0046}_{-0.0046}$
c_{HWB}	0.0020	$^{+0.0044}_{-0.0042}$	$^{+0.0090}_{-0.0079}$	0.0019	$^{+0.0042}_{-0.0041}$	$^{+0.0083}_{-0.0081}$	$^{+0.0043}_{-0.0041}$	$^{+0.0088}_{-0.0077}$	$^{+0.0042}_{-0.0042}$	$^{+0.0083}_{-0.0082}$
c_{HG}	0.0011	$^{+0.0030}_{-0.0028}$	$^{+0.0062}_{-0.0053}$	0.0011	$^{+0.0029}_{-0.0028}$	$^{+0.0059}_{-0.0055}$	$^{+0.0030}_{-0.0027}$	$^{+0.0061}_{-0.0052}$	$^{+0.0029}_{-0.0028}$	$^{+0.0059}_{-0.0054}$
c_W	−0.047	$^{+0.098}_{-0.11}$	$^{+0.19}_{-0.21}$	−0.047	$^{+0.098}_{-0.11}$	$^{+0.19}_{-0.21}$	$^{+0.096}_{-0.10}$	$^{+0.18}_{-0.21}$	$^{+0.096}_{-0.10}$	$^{+0.18}_{-0.21}$
c_G	0.32	$^{+1.5}_{-1.2}$	$^{+3.4}_{-2.0}$	0.077	$^{+0.13}_{-0.30}$	$^{+0.22}_{-0.40}$	$^{+1.5}_{-1.1}$	$^{+3.4}_{-1.9}$	$^{+0.18}_{-0.20}$	$^{+0.28}_{-0.30}$
c_{uW}	−0.039	$^{+0.080}_{-0.087}$	$^{+0.15}_{-0.18}$	−0.039	$^{+0.080}_{-0.087}$	$^{+0.15}_{-0.18}$	$^{+0.079}_{-0.083}$	$^{+0.15}_{-0.17}$	$^{+0.079}_{-0.083}$	$^{+0.15}_{-0.17}$
c_{uB}	−0.021	$^{+0.043}_{-0.046}$	$^{+0.082}_{-0.094}$	−0.021	$^{+0.043}_{-0.046}$	$^{+0.082}_{-0.094}$	$^{+0.042}_{-0.045}$	$^{+0.080}_{-0.092}$	$^{+0.042}_{-0.045}$	$^{+0.080}_{-0.092}$
c_{uG}	0.030	$^{+0.078}_{-0.078}$	$^{+0.16}_{-0.14}$	0.030	$^{+0.077}_{-0.078}$	$^{+0.16}_{-0.15}$	$^{+0.079}_{-0.074}$	$^{+0.16}_{-0.14}$	$^{+0.078}_{-0.075}$	$^{+0.16}_{-0.14}$
c_{uH}	−0.29	$^{+1.4}_{-1.5}$	$^{+2.7}_{-3.0}$	−0.30	$^{+1.4}_{-1.6}$	$^{+2.6}_{-3.3}$	$^{+1.4}_{-1.5}$	$^{+2.7}_{-3.0}$	$^{+1.4}_{-1.5}$	$^{+2.5}_{-3.3}$
c_{dH}	0.63	$^{+1.4}_{-1.3}$	$^{+2.9}_{-2.5}$	0.61	$^{+1.3}_{-1.3}$	$^{+2.5}_{-2.7}$	$^{+1.4}_{-1.3}$	$^{+2.8}_{-2.4}$	$^{+1.3}_{-1.4}$	$^{+2.5}_{-2.7}$
c_{eH}	5.8	$^{+13}_{-12}$	–	1.9	$^{+5.6}_{-5.7}$	$^{+8.9}_{-8.9}$	$^{+13}_{-12}$	–	$^{+9.1}_{-5.2}$	$^{+12}_{-8.4}$
$c_{Hq}^{(3)}$	−0.027	$^{+0.091}_{-0.081}$	$^{+0.19}_{-0.15}$	−0.037	$^{+0.096}_{-0.21}$	$^{+0.17}_{-0.34}$	$^{+0.10}_{-0.089}$	$^{+0.20}_{-0.17}$	$^{+0.085}_{-0.12}$	$^{+0.16}_{-0.29}$
$c_{Hq}^{(1)}$	1.9	$^{+1.7}_{-2.0}$	$^{+3.1}_{-4.1}$	0.029	$^{+0.20}_{-0.22}$	$^{+0.35}_{-0.37}$	$^{+2.0}_{-2.3}$	$^{+3.6}_{-4.8}$	$^{+0.30}_{-0.28}$	$^{+0.44}_{-0.41}$
$c_{Hl}^{(3)}$	−0.15	$^{+0.28}_{-0.28}$	$^{+0.52}_{-0.58}$	−0.15	$^{+0.28}_{-0.28}$	$^{+0.52}_{-0.58}$	$^{+0.26}_{-0.28}$	$^{+0.50}_{-0.57}$	$^{+0.26}_{-0.28}$	$^{+0.50}_{-0.57}$
$c_{Hl}^{(1)}$	–	–	–	4.4	$^{+6.8}_{-6.9}$	$^{+12}_{-12}$	$^{+13}_{-15}$	–	$^{+16}_{-7.8}$	–
c_{Hu}	−0.97	$^{+0.79}_{-0.67}$	$^{+1.7}_{-1.2}$	−0.14	$^{+0.30}_{-0.24}$	$^{+0.51}_{-0.41}$	$^{+0.96}_{-0.82}$	$^{+2.0}_{-1.5}$	$^{+0.32}_{-0.43}$	$^{+0.49}_{-0.61}$
c_{Hd}	3.4	$^{+2.2}_{-2.6}$	$^{+4.0}_{-5.4}$	0.070	$^{+0.33}_{-0.36}$	$^{+0.55}_{-0.60}$	$^{+2.7}_{-3.1}$	$^{+4.9}_{-6.5}$	$^{+0.51}_{-0.44}$	$^{+0.73}_{-0.67}$

Parameter	Observed						Expected			
	linear			linear+quadratic			linear		linear+quadratic	
	Value	Uncertainty		Value	Uncertainty		Uncertainty		Uncertainty	
		68% CL	95% CL		68% CL	95% CL	68% CL	95% CL	68% CL	95% CL
$c_{H\Box}$	0.68	$^{+1.5}_{-1.4}$	$^{+3.1}_{-2.7}$	0.63	$^{+1.4}_{-1.4}$	$^{+2.7}_{-2.7}$	$^{+1.5}_{-1.4}$	$^{+3.0}_{-2.6}$	$^{+1.4}_{-1.4}$	$^{+2.8}_{-2.9}$
c_{HD}	−0.21	$^{+0.42}_{-0.44}$	$^{+0.79}_{-0.91}$	−0.21	$^{+0.42}_{-0.45}$	$^{+0.79}_{-0.93}$	$^{+0.41}_{-0.43}$	$^{+0.77}_{-0.88}$	$^{+0.40}_{-0.43}$	$^{+0.76}_{-0.89}$
$c_{qq}^{(3)}$	0.72	$^{+3.4}_{-2.8}$	$^{+7.3}_{-5.0}$	−0.20	$^{+0.55}_{-0.18}$	$^{+0.69}_{-0.32}$	$^{+3.2}_{-2.6}$	$^{+6.8}_{-4.7}$	$^{+0.29}_{-0.31}$	$^{+0.43}_{-0.46}$
$c_{qq}^{(3)\prime}$	0.042	$^{+0.37}_{-0.28}$	$^{+0.83}_{-0.50}$	−0.30	$^{+0.52}_{-0.19}$	$^{+0.67}_{-0.34}$	$^{+0.38}_{-0.29}$	$^{+0.84}_{-0.49}$	$^{+0.21}_{-0.44}$	$^{+0.36}_{-0.60}$
$c_{qq}^{(1)}$	2.0	$^{+14}_{-11}$	–	−0.20	$^{+0.69}_{-0.30}$	$^{+0.90}_{-0.52}$	$^{+14}_{-11}$	–	$^{+0.44}_{-0.45}$	$^{+0.67}_{-0.68}$
$c_{qq}^{(1)\prime}$	0.097	$^{+0.79}_{-0.60}$	$^{+1.7}_{-1.0}$	−0.50	$^{+0.92}_{-0.31}$	$^{+1.2}_{-0.57}$	$^{+0.79}_{-0.61}$	$^{+1.8}_{-1.0}$	$^{+0.39}_{-0.73}$	$^{+0.66}_{-1.0}$
c'_{ll}	0.30	$^{+0.53}_{-0.56}$	$^{+1.1}_{-1.0}$	0.30	$^{+0.52}_{-0.56}$	$^{+1.1}_{-1.0}$	$^{+0.55}_{-0.51}$	$^{+1.1}_{-0.98}$	$^{+0.54}_{-0.51}$	$^{+1.1}_{-0.99}$
c_{uu}	1.4	$^{+13}_{-9.9}$	–	−0.25	$^{+0.85}_{-0.37}$	$^{+1.1}_{-0.64}$	$^{+13}_{-9.9}$	–	$^{+0.53}_{-0.56}$	$^{+0.81}_{-0.84}$
c'_{uu}	0.098	$^{+0.80}_{-0.61}$	$^{+1.8}_{-1.1}$	−0.50	$^{+0.92}_{-0.31}$	$^{+1.2}_{-0.57}$	$^{+0.81}_{-0.61}$	$^{+1.8}_{-1.1}$	$^{+0.39}_{-0.72}$	$^{+0.66}_{-1.0}$
$c_{qu}^{(1)}$	–	–	–	−0.30	$^{+1.1}_{-0.48}$	$^{+1.4}_{-0.81}$	–	–	$^{+0.68}_{-0.70}$	$^{+1.0}_{-1.0}$
$c_{qu}^{(8)}$	0.15	$^{+1.3}_{-0.97}$	$^{+2.8}_{-1.7}$	−1.8	$^{+2.6}_{-0.82}$	$^{+3.3}_{-1.5}$	$^{+1.3}_{-0.97}$	$^{+2.8}_{-1.7}$	$^{+0.84}_{-2.3}$	$^{+1.5}_{-3.0}$
$c_{qd}^{(1)}$	–	–	–	0.75	$^{+0.94}_{-2.4}$	$^{+1.7}_{-3.2}$	–	–	$^{+1.5}_{-1.5}$	$^{+2.3}_{-2.3}$
$c_{qd}^{(8)}$	0.53	$^{+5.5}_{-4.3}$	$^{+12}_{-7.5}$	−2.3	$^{+4.8}_{-2.3}$	$^{+6.4}_{-3.9}$	$^{+5.6}_{-4.3}$	$^{+12}_{-7.5}$	$^{+2.4}_{-4.1}$	$^{+4.0}_{-5.8}$
$c_{ud}^{(1)}$	–	–	–	0.75	$^{+0.93}_{-2.4}$	$^{+1.7}_{-3.1}$	–	–	$^{+1.5}_{-1.5}$	$^{+2.3}_{-2.3}$
$c_{ud}^{(8)}$	0.53	$^{+5.5}_{-4.3}$	$^{+12}_{-7.5}$	−2.5	$^{+5.1}_{-2.0}$	$^{+6.7}_{-3.6}$	$^{+5.6}_{-4.4}$	$^{+12}_{-7.6}$	$^{+2.4}_{-4.1}$	$^{+4.0}_{-5.7}$

Higgs combination STXS interpretation

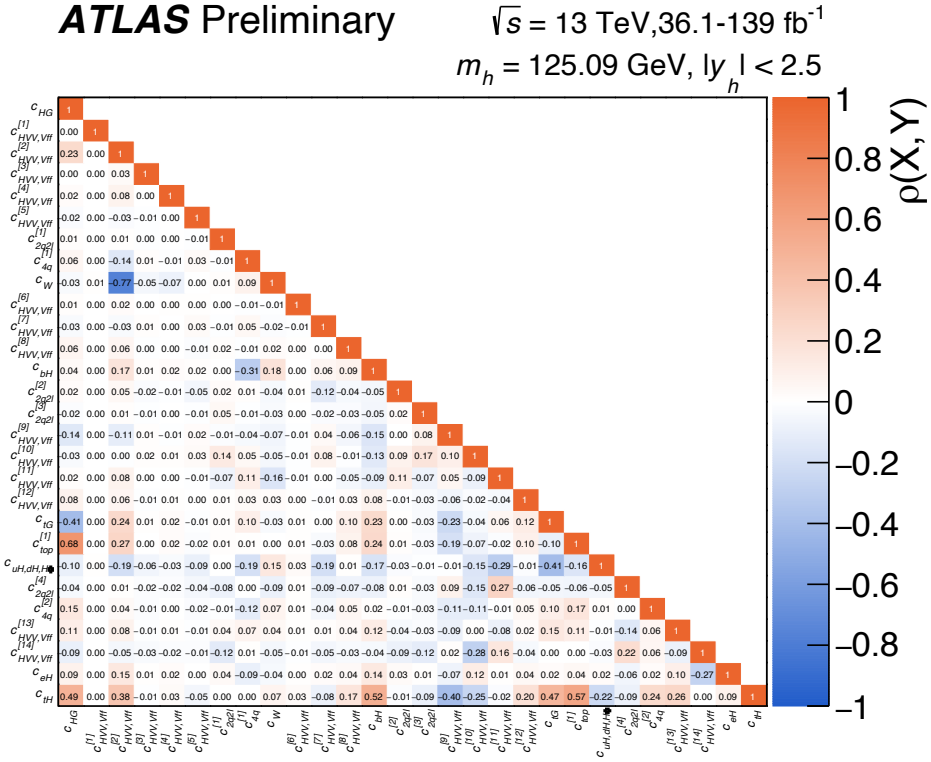
- **Observed correlations** between linear combinations of Wilson coefficients & **list of coefficients** and operators
  - $c_{H\Box}$ acts as normalization in all bins and is thus excluded from fit

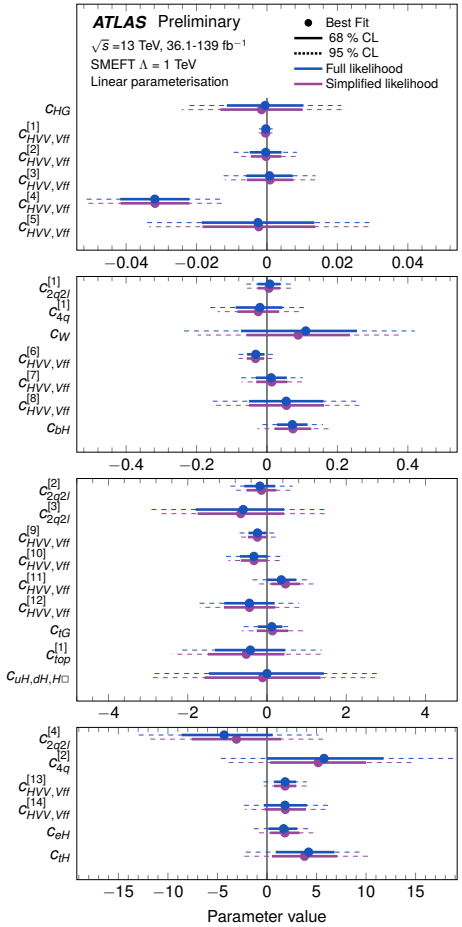


Wilson coefficient	Operator	Wilson coefficient	Operator
$c_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$	c_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{H}\,G^A_{\mu\nu}$
c_{HDD}	$\left(H^\dagger D^\mu H\right)^*\left(H^\dagger D_\mu H\right)$	c_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{H}\,W^I_{\mu\nu}$
c_{HG}	$H^\dagger H\,G^A_{\mu\nu}G^{A\mu\nu}$	c_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{H}\,B_{\mu\nu}$
c_{HB}	$H^\dagger H\,B_{\mu\nu}B^{\mu\nu}$	c'_{ll}	$(\bar{l}_p\gamma_\mu l_t)(\bar{l}_r\gamma^\mu l_s)$
c_{HW}	$H^\dagger H\,W^I_{\mu\nu}W^{I\mu\nu}$	$c^{(1)}_{qq}$	$(\bar{q}_p\gamma_\mu q_t)(\bar{q}_r\gamma^\mu q_s)$
c_{HWB}	$H^\dagger\tau^I H\,W^I_{\mu\nu}B^{\mu\nu}$	$c^{(3)}_{qq}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$
c_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$	c_{qq}	$(\bar{q}_p\gamma_\mu q_t)(\bar{q}_r\gamma^\mu q_s)$
c_{uH}	$(H^\dagger H)(\bar{q}_p u_r\widetilde{H})$	$c^{(31)}_{qq}$	$(\bar{q}_p\gamma_\mu\tau^I q_t)(\bar{q}_r\gamma^\mu\tau^I q_s)$
c_{dH}	$(H^\dagger H)(\bar{q}_p d_r\widetilde{H})$	c_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$
$c^{(1)}_{Hl}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_p\gamma^\mu l_r)$	$c^{(1)}_{uu}$	$(\bar{u}_p\gamma_\mu u_t)(\bar{u}_r\gamma^\mu u_s)$
$c^{(3)}_{Hl}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_p\tau^I\gamma^\mu l_r)$	$c^{(1)}_{qu}$	$(\bar{q}_p\gamma_\mu q_t)(\bar{u}_r\gamma^\mu u_s)$
c_{He}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_p\gamma^\mu e_r)$	$c^{(8)}_{ud}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$
$c^{(1)}_{Hq}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p\gamma^\mu q_r)$	$c^{(8)}_{qu}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
$c^{(3)}_{Hq}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q}_p\tau^I\gamma^\mu q_r)$	$c^{(8)}_{qd}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$
c_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p\gamma^\mu u_r)$	c_W	$\epsilon^{IJK}W^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$
c_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p\gamma^\mu d_r)$	c_G	$f^{ABC}G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$

Global SMEFT fit: Higgs + EW + EWPO

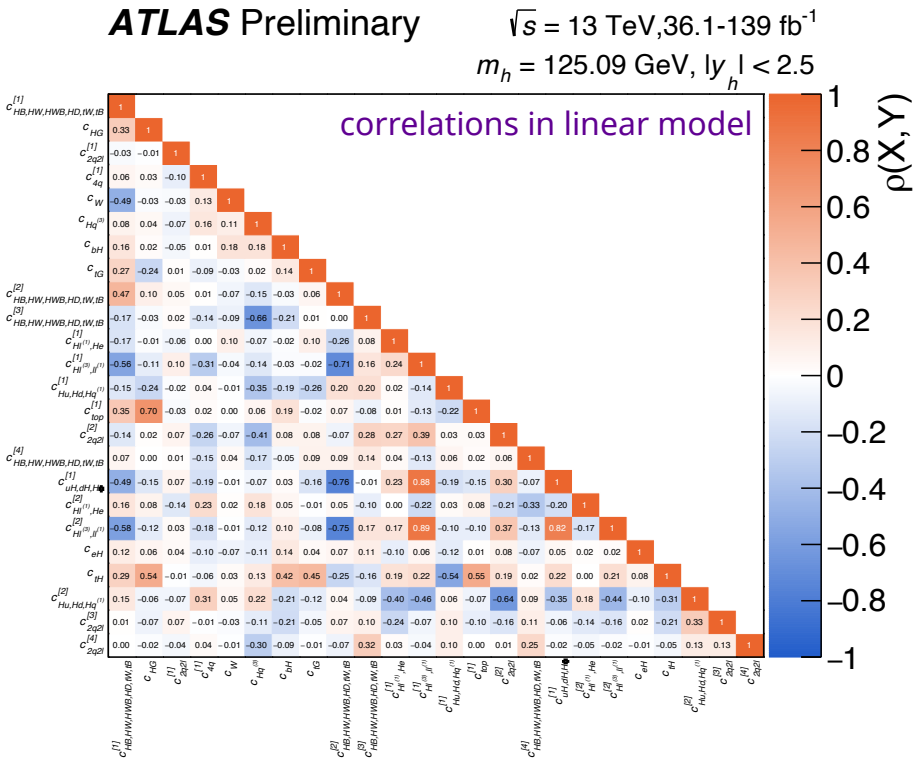
- **Higgs + EW + EWPO**: **correlations** and **simplified likelihood model**

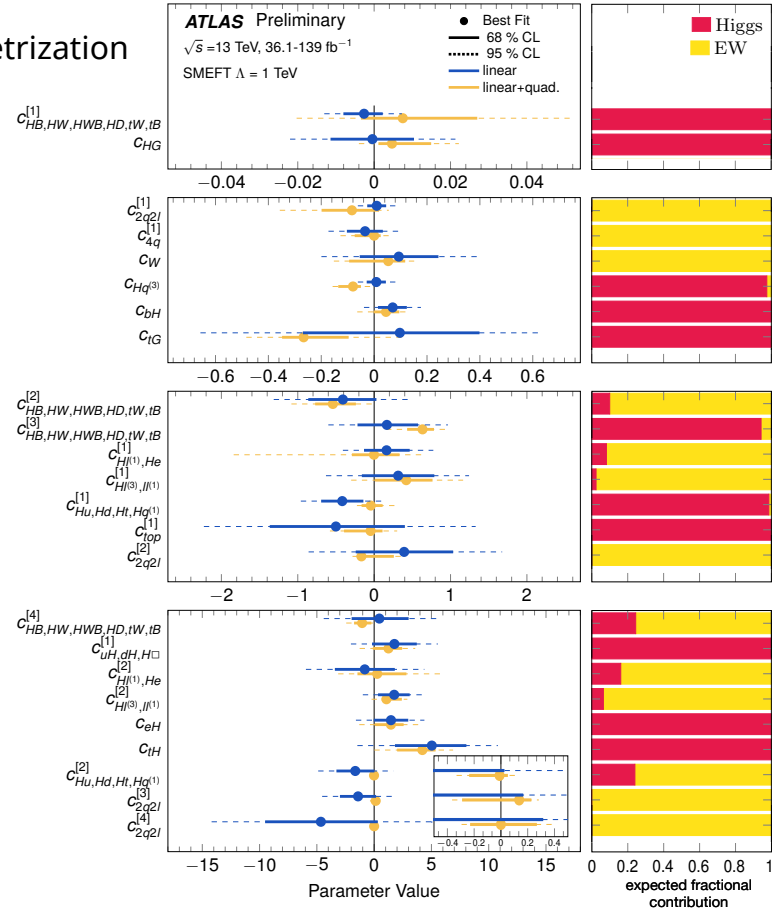




Global SMEFT fit: Higgs + EW + EWPO

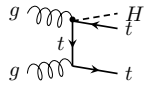
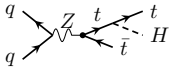
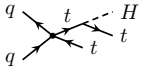
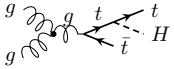
- **ATLAS-only results**: results in linear and linear + quadratic parametrization

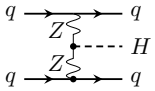
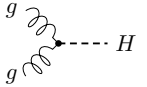
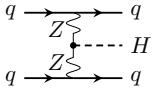
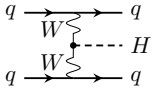
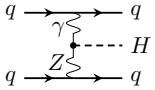
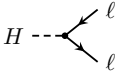


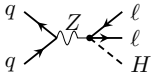
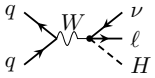
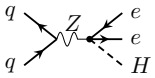
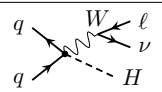
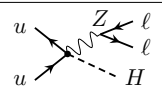


Examples of operators and diagrams

- Examples of **processes modified per Wilson coefficient**, taken from ATLAS-CONF-2020-053

Coefficient	Operator	Example process
c_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\widetilde{H}\, G^A_{\mu\nu}$	
c_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \widetilde{H}\, W^I_{\mu\nu}$	
c_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{H}\, B_{\mu\nu}$	
$c^{(1)}_{qq}$	$(\bar{q}_p \gamma_\mu q_t)(\bar{q}_r \gamma^\mu q_s)$	
$c^{(3)}_{qq}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	
c_{qq}	$(\bar{q}_p \gamma_\mu q_t)(\bar{q}_r \gamma^\mu q_s)$	
$c^{(31)}_{qq}$	$(\bar{q}_p \gamma_\mu \tau^I q_t)(\bar{q}_r \gamma^\mu \tau^I q_s)$	
c_{uu}	$(\bar{u}_p \gamma_\mu u_r)(\bar{u}_s \gamma^\mu u_t)$	
$c^{(1)}_{uu}$	$(\bar{u}_p \gamma_\mu u_t)(\bar{u}_r \gamma^\mu u_s)$	
$c^{(1)}_{qu}$	$(\bar{q}_p \gamma_\mu q_t)(\bar{u}_r \gamma^\mu u_s)$	
$c^{(8)}_{ud}$	$(\bar{u}_p \gamma_\mu T^A u_r)(\bar{d}_s \gamma^\mu T^A d_t)$	
$c^{(8)}_{qu}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{u}_s \gamma^\mu T^A u_t)$	
$c^{(8)}_{qd}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{d}_s \gamma^\mu T^A d_t)$	
c_G	$f^{ABC} G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	

Coefficient	Operator	Example process
c_{HDD}	$\left(H^\dagger D^\mu H\right)^* \left(H^\dagger D_\mu H\right)$	
c_{HG}	$H^\dagger H\, G^A_{\mu\nu} G^{A\mu\nu}$	
c_{HB}	$H^\dagger H\, B_{\mu\nu} B^{\mu\nu}$	
c_{HW}	$H^\dagger H\, W^I_{\mu\nu} W^{I\mu\nu}$	
c_{HWB}	$H^\dagger \tau^I H\, W^I_{\mu\nu} B^{\mu\nu}$	
c_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$	

Coefficient	Operator	Example process
$c^{(1)}_{Hl}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)$	
$c^{(3)}_{Hl}$	$(H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{l}_p \tau^I \gamma^\mu l_r)$	
c_{He}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{e}_p \gamma^\mu e_r)$	
$c^{(1)}_{Hq}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{q}_p \gamma^\mu q_r)$	
$c^{(3)}_{Hq}$	$(H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{q}_p \tau^I \gamma^\mu q_r)$	
c_{Hu}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$	
c_{Hd}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$