Interpretations of Higgs measurements at ATLAS

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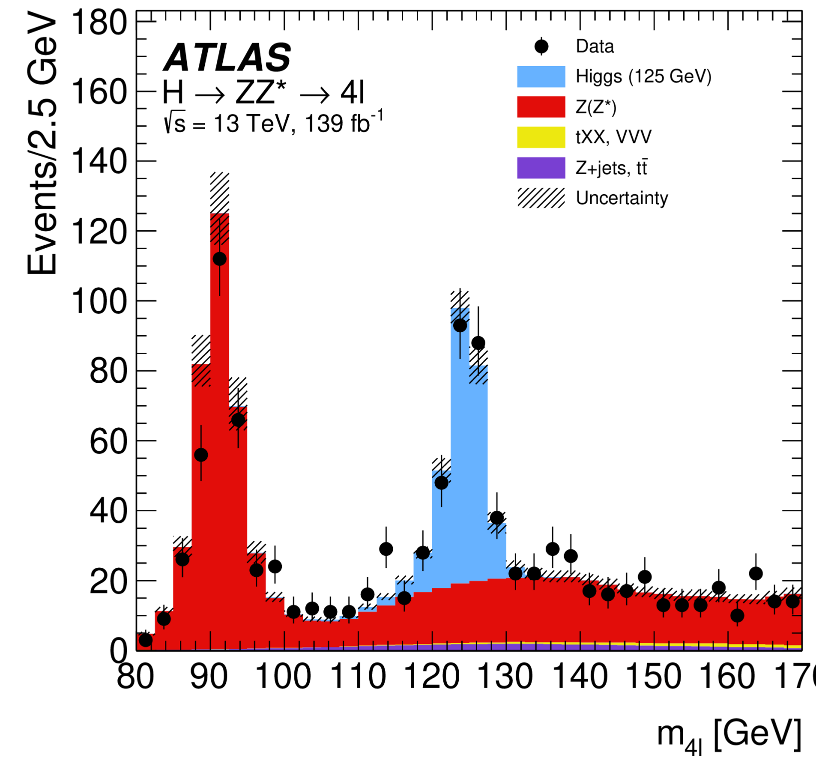
Introduction

Ever since the discovery of the Higgs boson in 2012: More precise measurements of its properties

- ✔ Higgs mass - 0.1-0.2%
- ✔ Spin = 0
- ✔ Higgs production
  - all major production modes discovered
- ✔ Higgs decays
  - most major decays discovered
  - now tackling rare decays like $H \to \mu\mu$, $H \to Z\gamma$
  - $H \to inv$ constrained to 11%
- ✔ Higgs couplings
  - assuming SM structure:
    - tested fermion and boson coupling strength
  - pure CP odd couplings to bosons excluded (> 5σ)
  - pure CP odd couplings to fermions excluded (> 3σ)

=> no disagreements from the SM predictions so far



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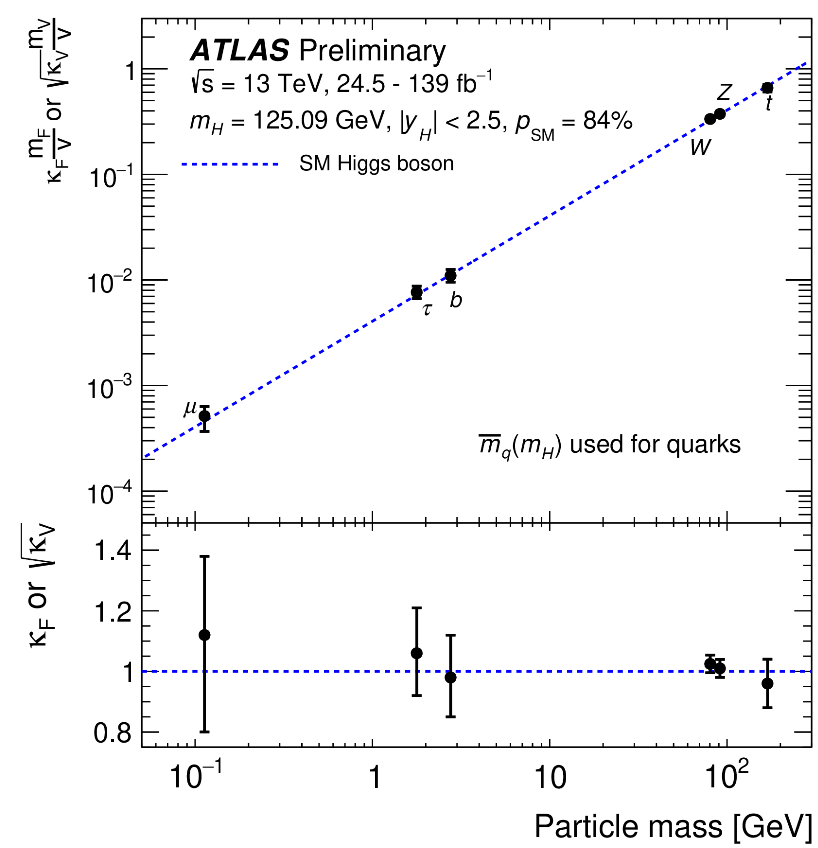

ATLAS-CONF-2020-027

Interpretations of Higgs measurements

Quantify the good agreement with the SM

=> check how much space there is for physics beyond the Standard Model

=> can be done for specific (benchmark) models, but also more model-independent

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1) Benchmark models, p.ex. SUSY (MSSM) models

2) SM EFT << focus of this talk

- constrain contributions of BSM physics at high energy scale Λ (decoupled from SM)

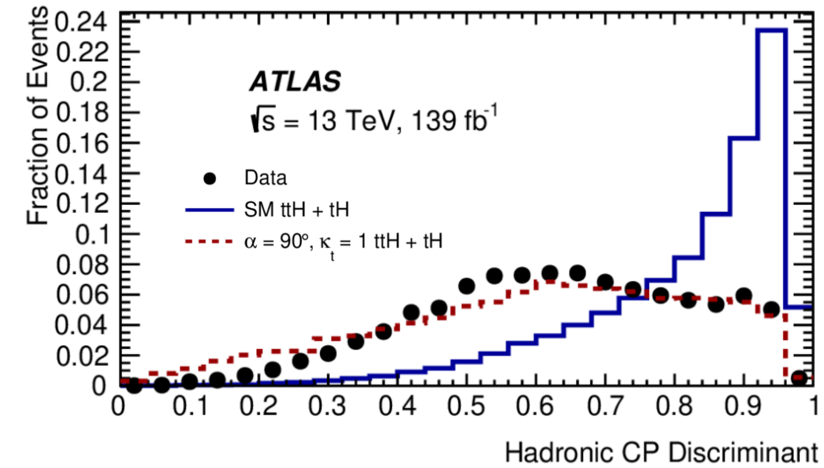
$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{i}^{N_{d6}} \frac{c_i}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_{j}^{N_{d8}} \frac{b_j}{\Lambda^4}\mathcal{O}_j^{(8)} + \ldots$$

c_i, b_j: Wilson coefficients

- constrain **d = 6 operators** (first lepton number conserving order)
- fully linearized ($1/\Lambda^2$ from SM-BSM interference) or including quadratic terms ($1/\Lambda^4$ from full BSM terms)
- effects on non-Higgs backgrounds are neglected
- Warsaw basis used for almost all measurements (with Madgraph5)

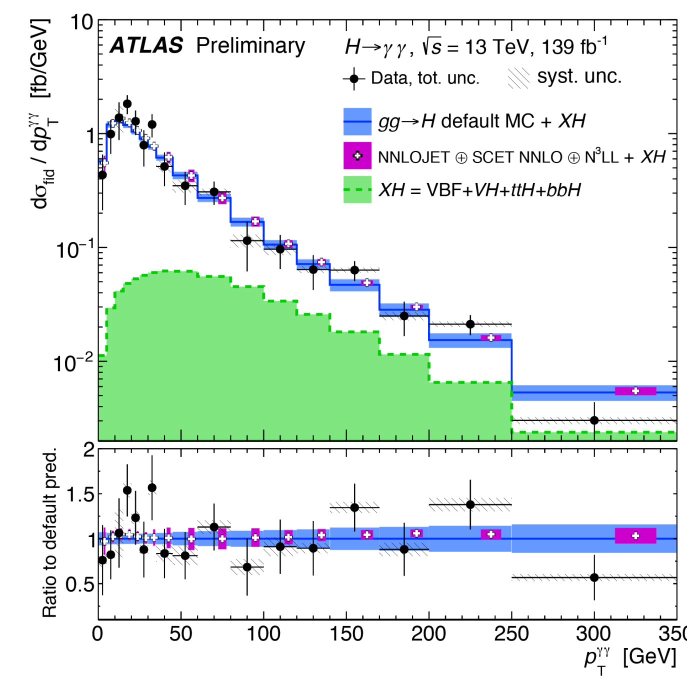
What to interpret?

- **Reconstructed distributions**
  - allow to fully optimize sensitivity
  - hard to reinterpret in different models



Phys. Rev. Lett. 125 (2020) 061802

- **Differential fiducial cross sections**
  - quite model-independent
  - allow for later reinterpretations
  - only currently feasible for a few decay channels (simple fiducial volumes possible due to well-understood backgrounds)
    - p.ex. $H \to \gamma\gamma$, $H \to 4l$



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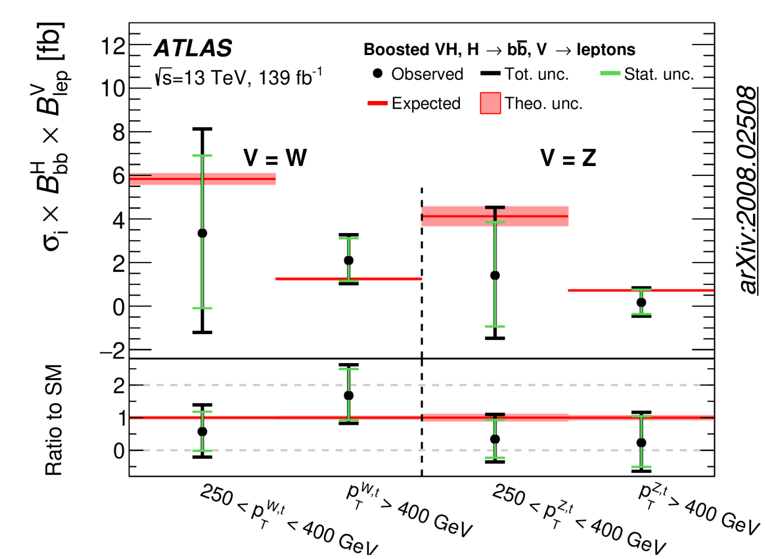
- **Simplified Template Cross section STXS (compromise)**
  - cross sections per production mode
  - additional binning in well-measured variables, with good sensitivity to BSM effects, and close to analysis selections
  - different stages evolving with collected LHC data
  - easy combination of decay channels: use complementarity in sensitivity



arXiv:2008.02508

Differential cross sections - H → γγ

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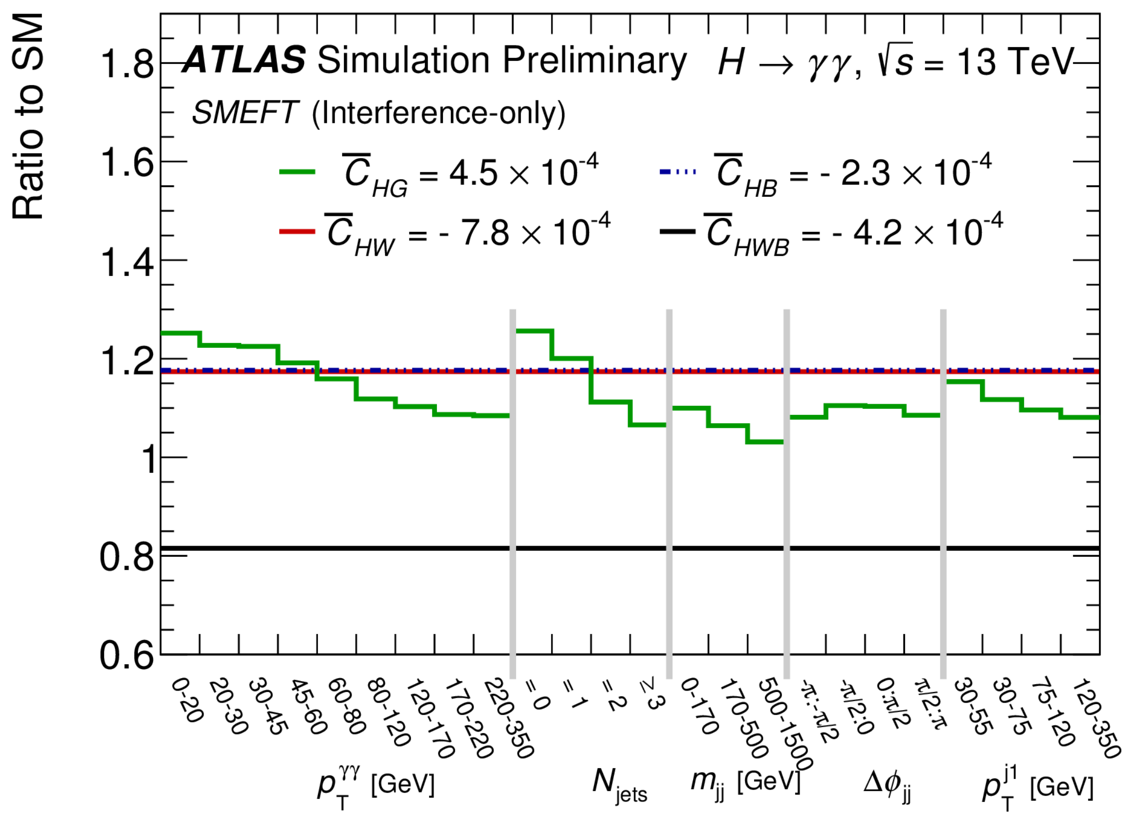
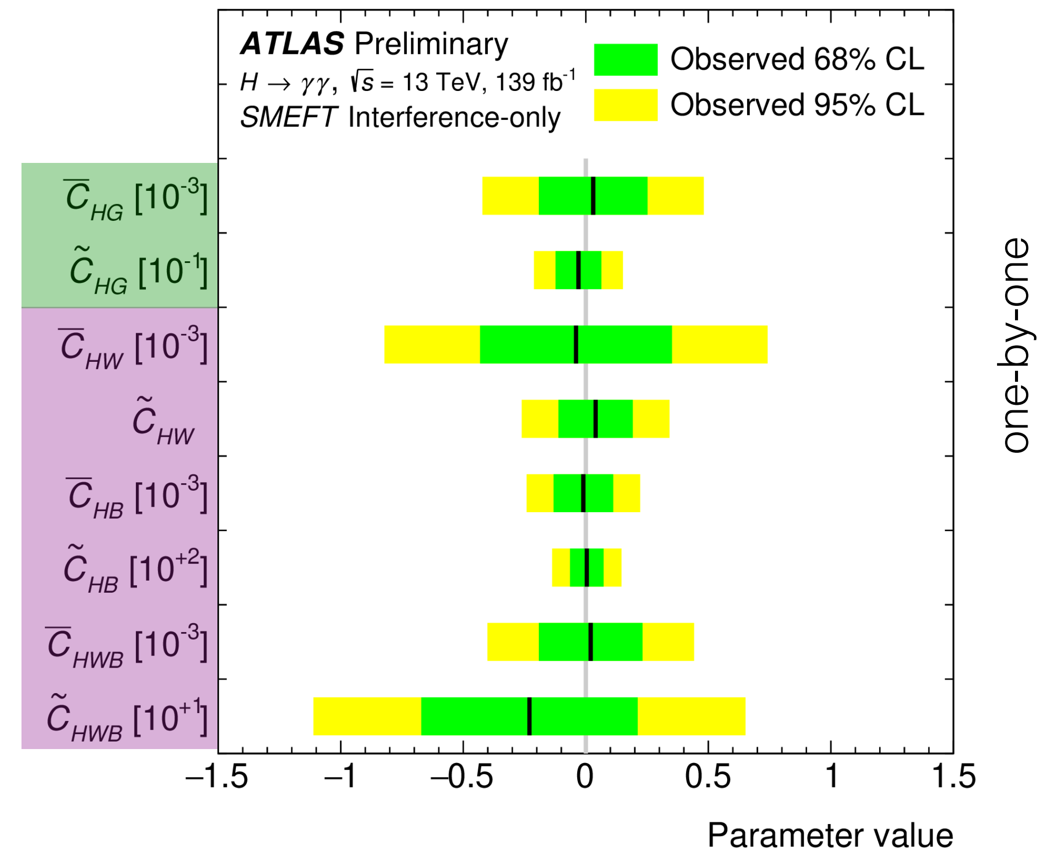
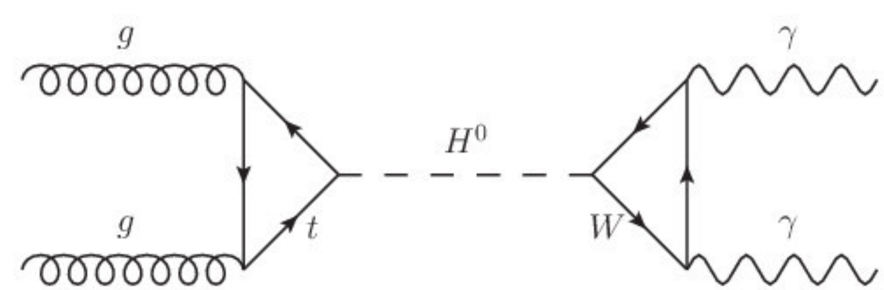
Measure simultaneously a number of differential cross sections (correlations: bootstrapping)





Warsaw basis

- Sensitivity to modified
  - Higgs-vector boson couplings (CHW, CHB, CHWB)
  - Higgs-gluon couplings (CHG)
  - CP even and CP odd (mainly from $\Delta\phi_{jj}$ and quadratic terms)



Differential cross sections - H → 4l

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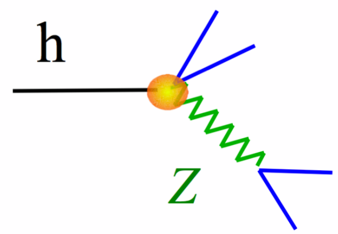
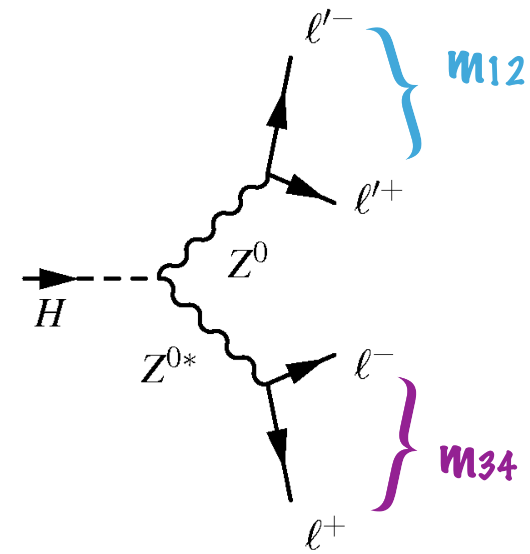
Pseudo-Observable Framework [JHEP10 (2018) 073]:

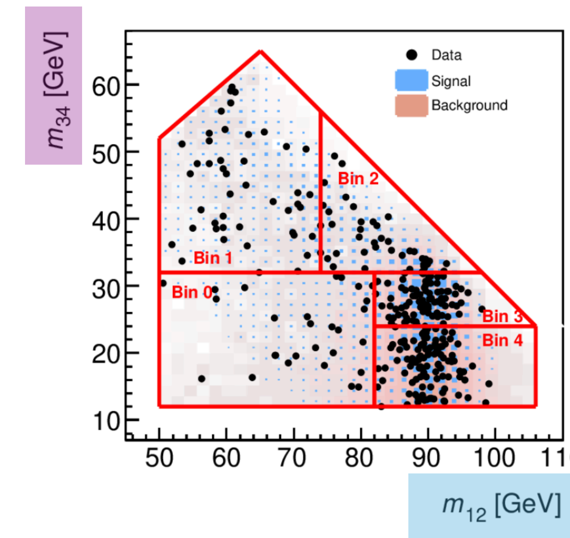
- modified contact terms between H, Z, and left- or right-handed leptons



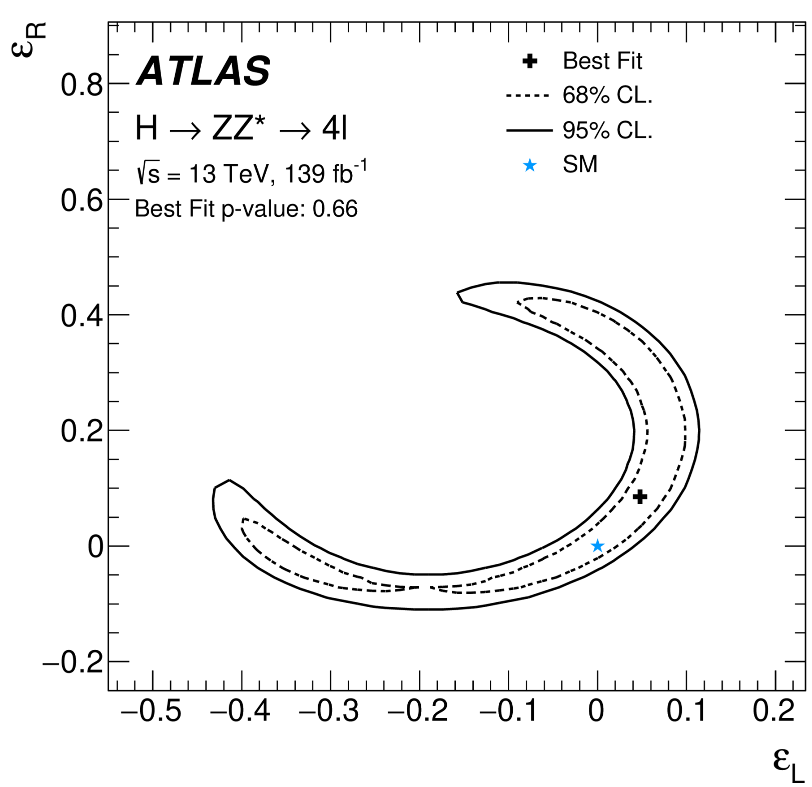
- impose different symmetries (p.ex. flavour)
- set other Pseudo-Observable parameters to 0

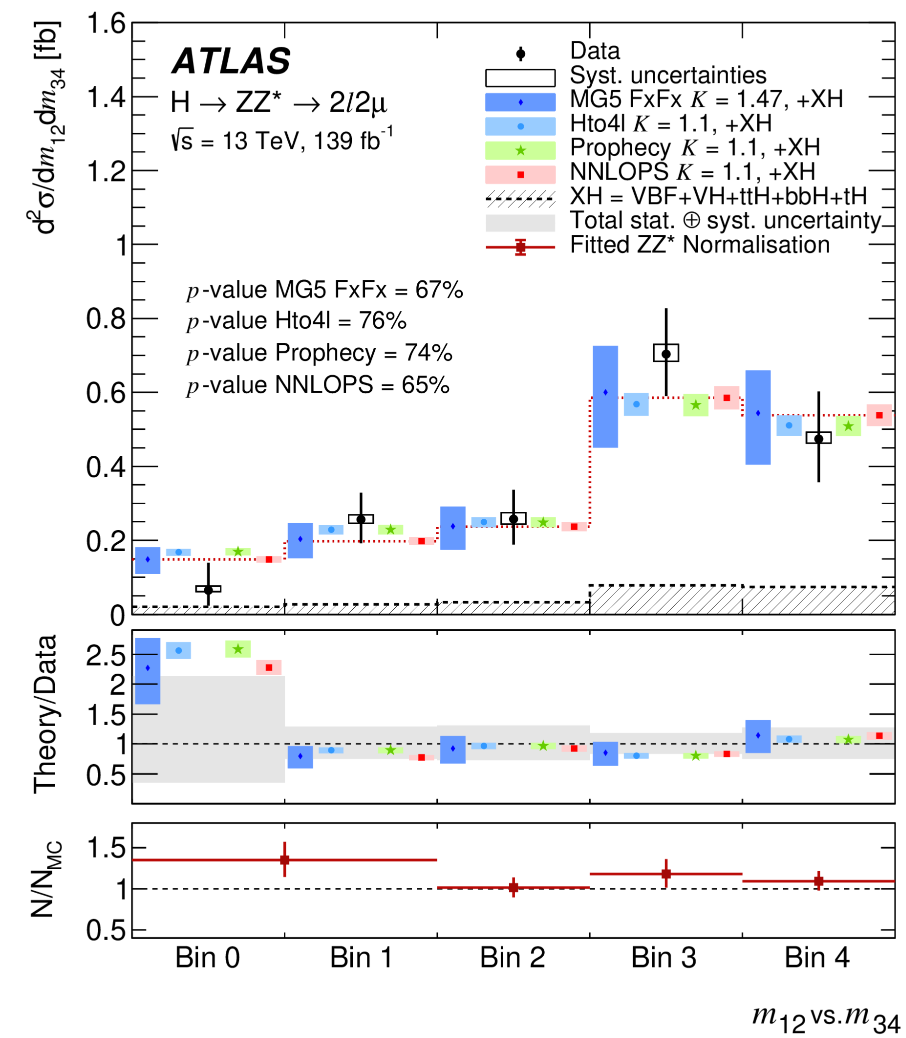
  => SM structure, only dilepton mass distributions are affected





flavour universal contact terms





STXS - H → 4l decay channel

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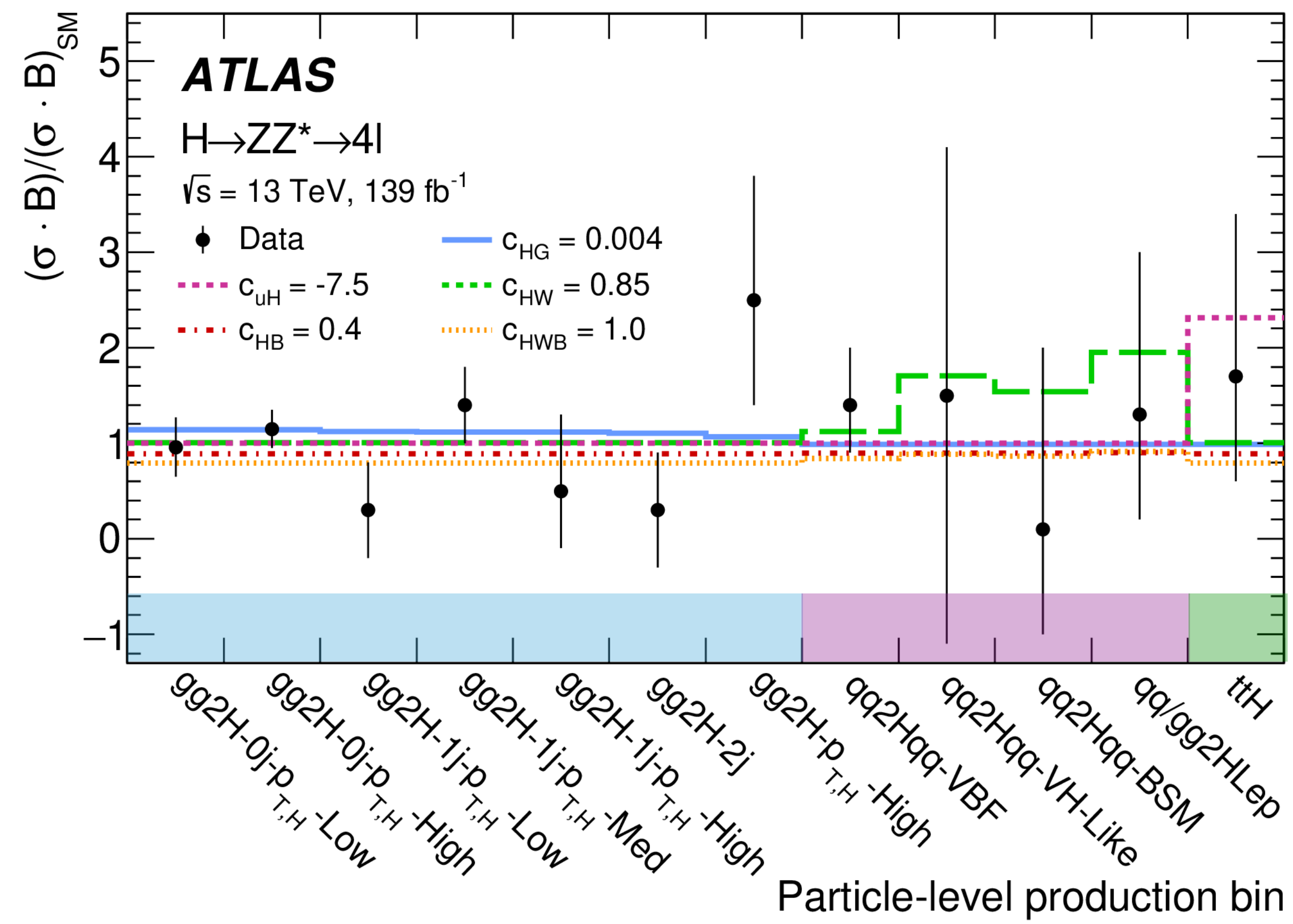
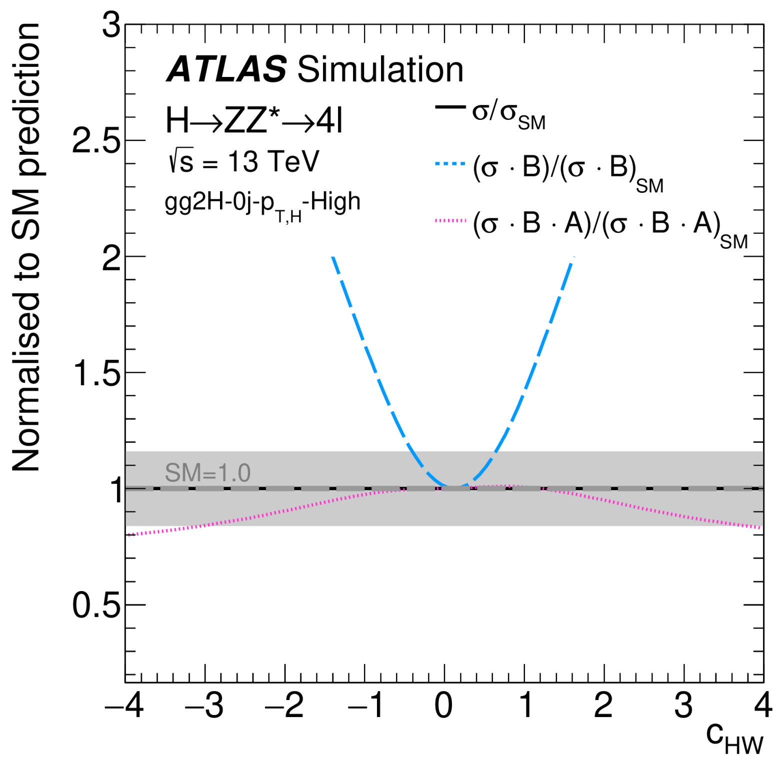
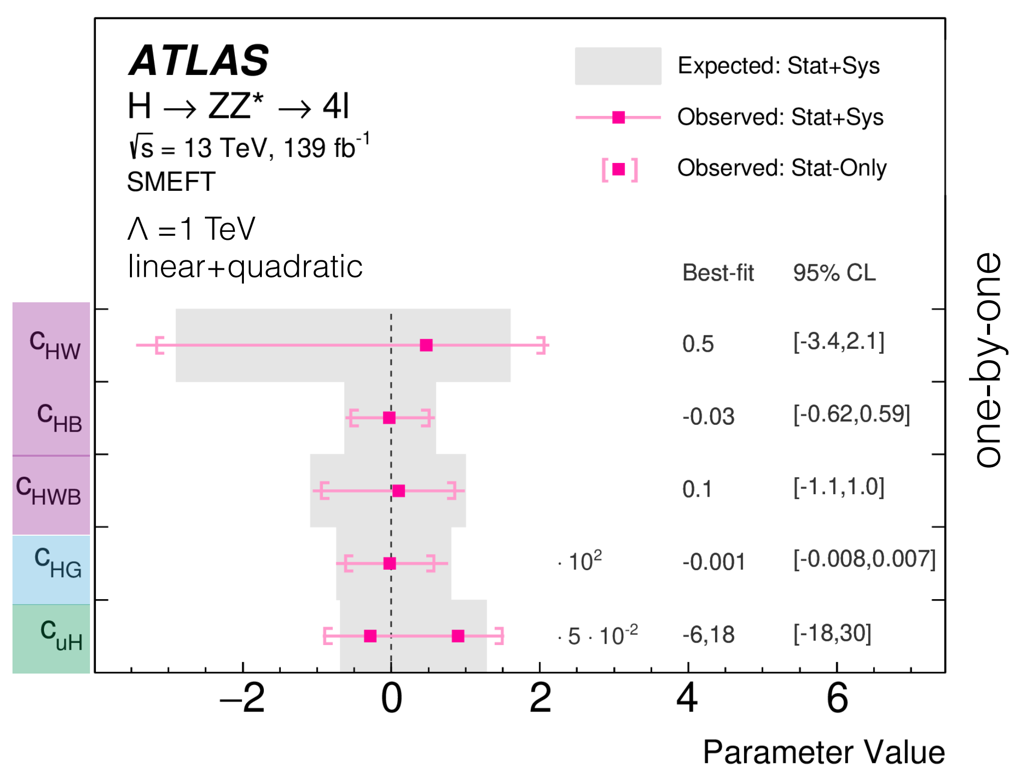
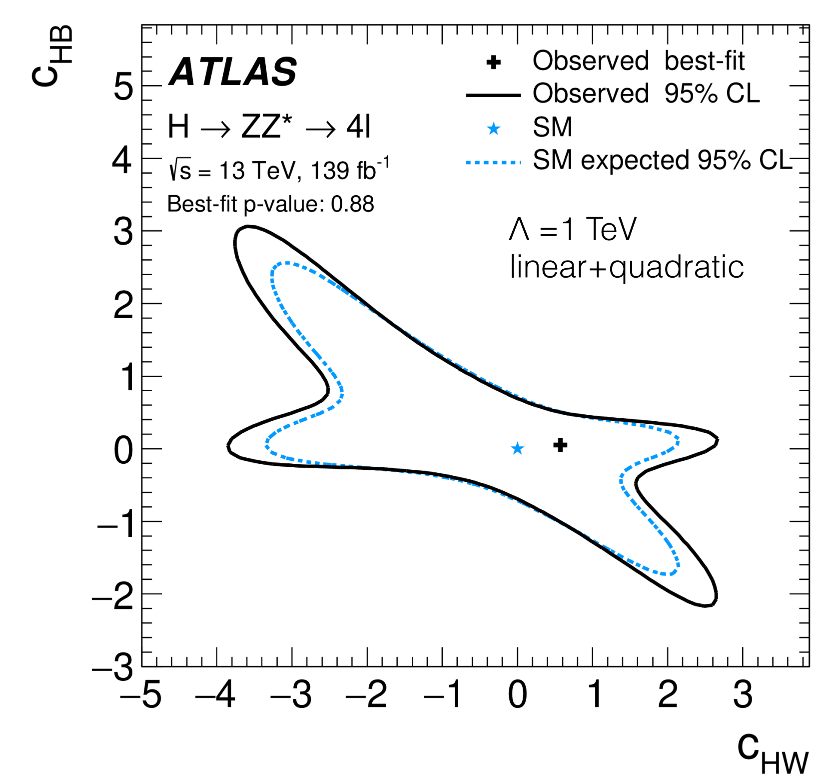
- Main sensitivity
  - ggF production (c_{HG})
  - VBF, VH, 4l decay (c_{HB} , c_{HWB}, c_{HW})
  - ttH ($|c_{uH}|$)
  - CP-even and CP-odd

- Decay acceptance effects (due to dilepton mass cuts mainly) taken into account









STXS - Combined measurement

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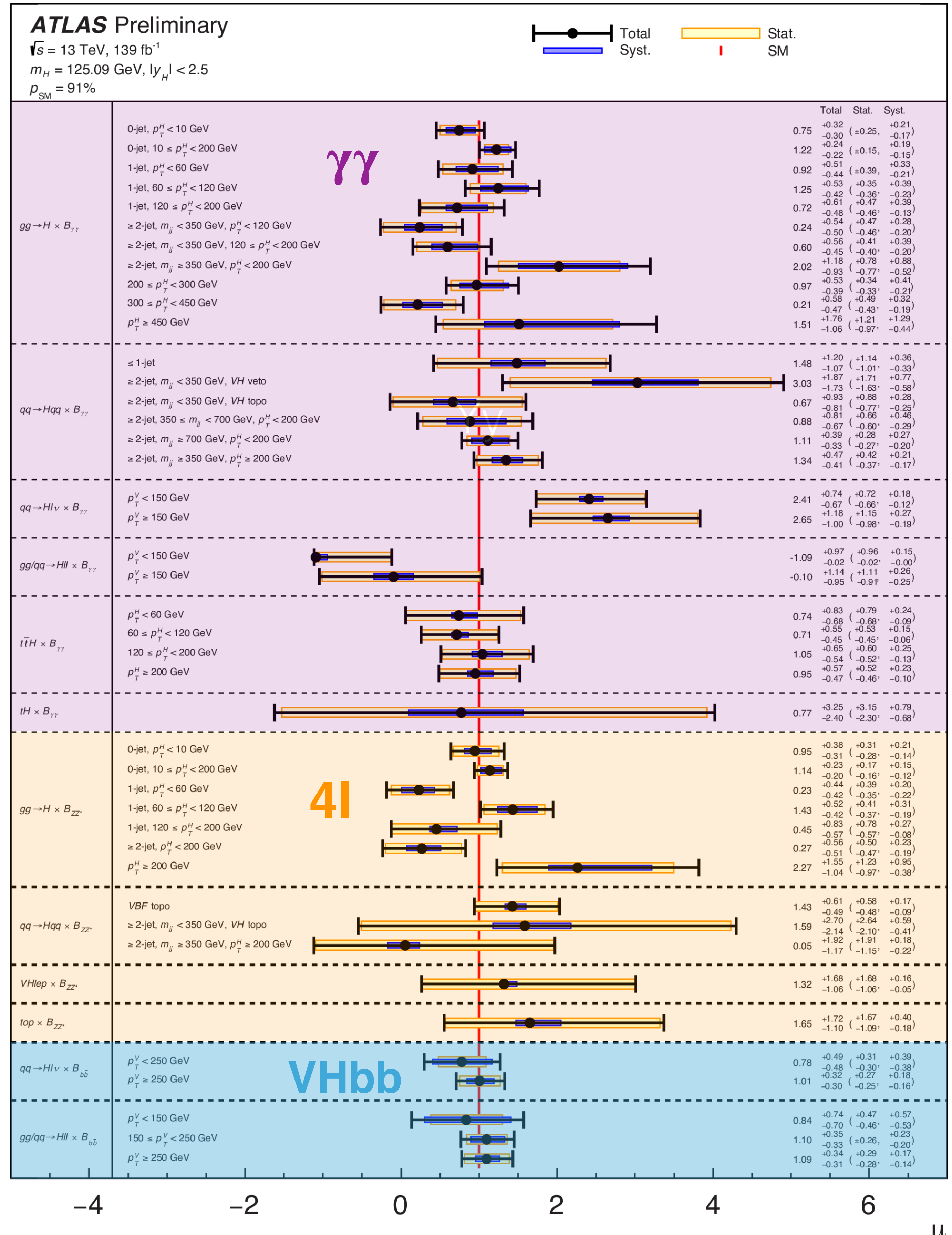
- Statistical combination of 3 analyses with full Run-2 dataset (139 fb[-1]):
  - H → γγ, H → 4l, VH (H → bb)

- signal strengths μ
- (XS*BR$_{meas}$/XS*BR$_{pred}$) are used to include the SM uncertainties

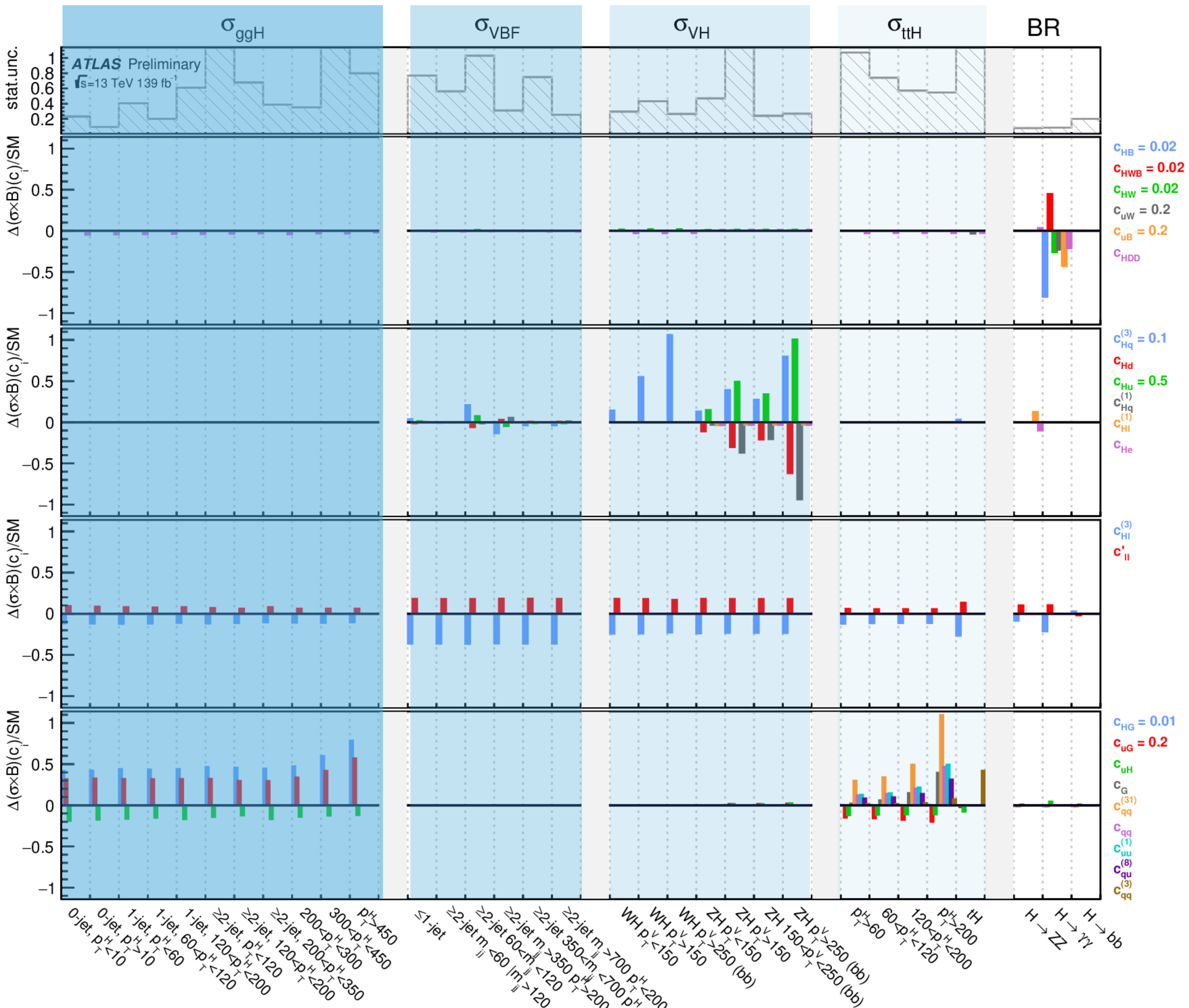
- to benefit from decays, actually treat every XS * BR product separately

- CP-even SMEFT parametrisation at leading process order
  - NLO QCD for ggF, ggZH, H → gg
  - NLO EW for H → γγ
  - LO for everything else

- 4l acceptance taken into account



STXS - Effect of operators on XS and BR

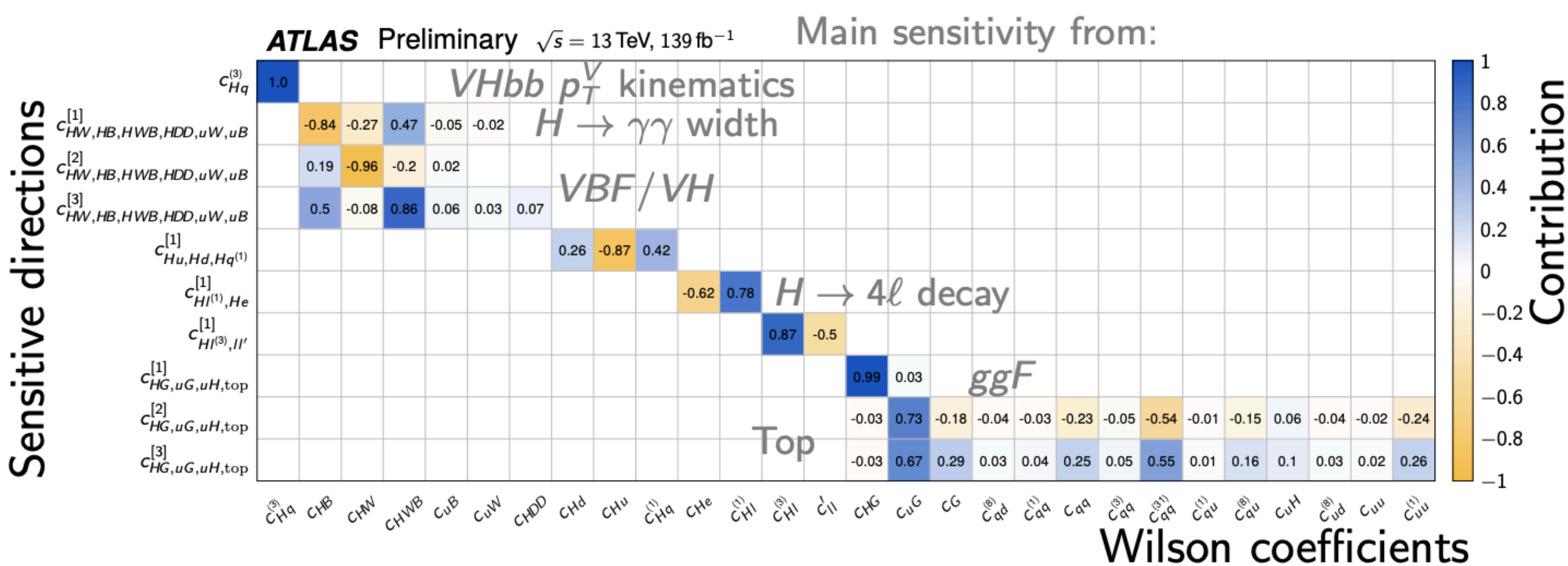


STXS -Rotation in coefficient space

- Test sensitivity to operators based on covariance matrix of STXS measurement with propagated linear EFT parameterization
  - perform eigenvector decomposition
  - identify groups of operators with similar impact on physics processes

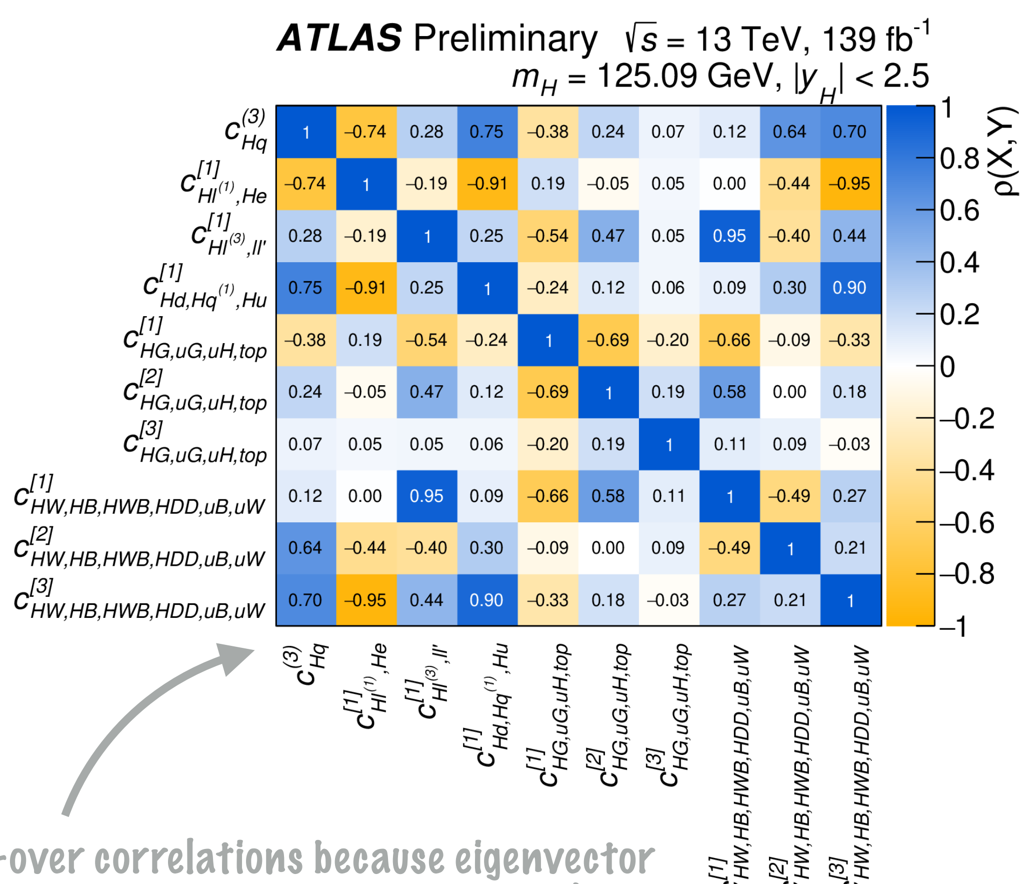
- For every identified group, perform eigenvector decomposition, and select the most sensitive => 10 parameters to fit

- It was checked that directions without sensitivity have no impact on fit results

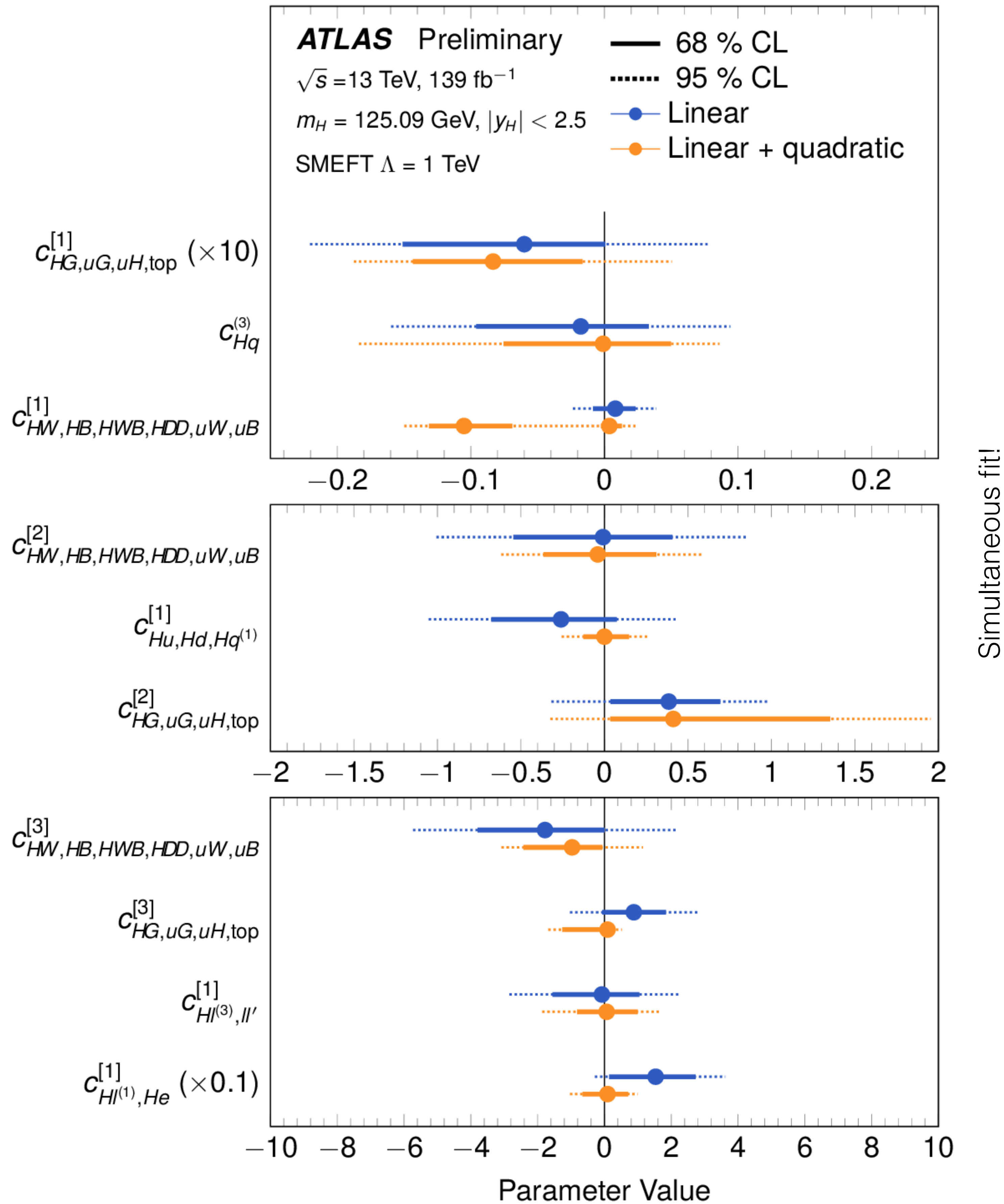


STXS - EFT

- **Simultaneous** fit of the 10 Wilson coefficients/groups
- ~tighter constraints from quadratic model => non-negligible impact
- idea is to use this as input to more global ATLAS EFT fits



Left-over correlations because eigenvector decomposition not exact to preserve physics connection



Conclusion

- So far all LHC measurements of the Higgs boson agree with the predictions of the SM

- Possible to quantify the agreement in terms of constraints
  - benchmark models
  - effective field theory (more model-independent)

- Best EFT constraints come from combination of measurements of different Higgs production modes and decay channels
  - simultaneous constraints on operators and groups of operators that the analysis is sensitive to
  - plan to include these fits into more global EFT combinations (first LHC, later other experiments)

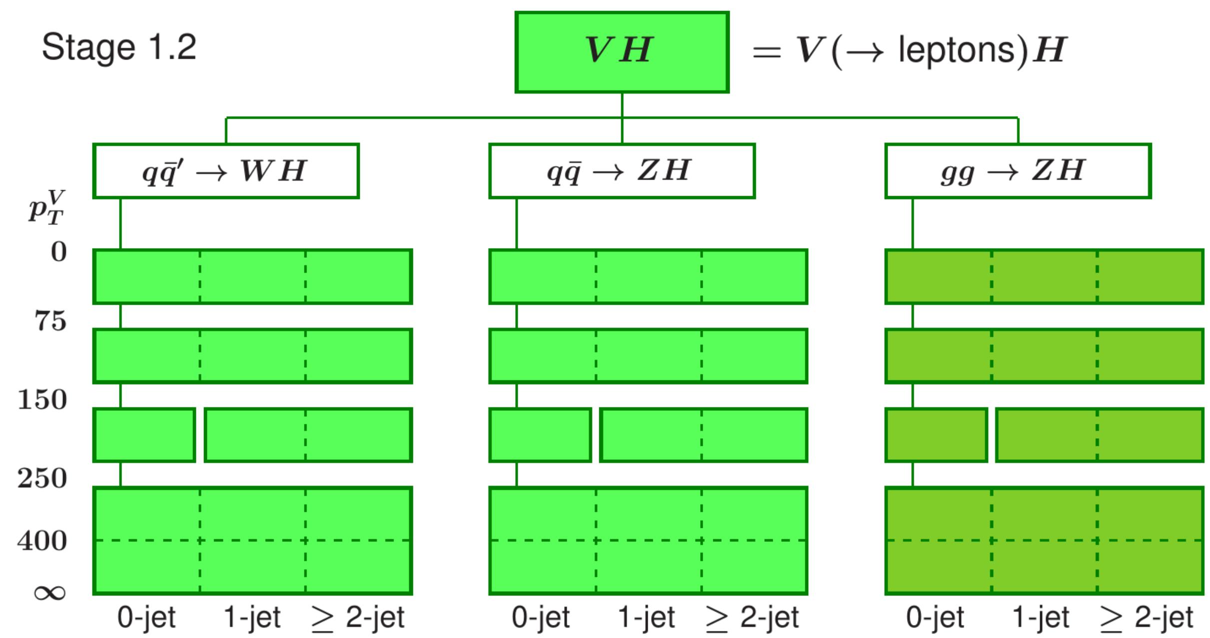
BACKUP

Simplified template cross sections (STXS)

Cross sections binned by production modes and additional kinematic/jet criteria

- first step: measurements in individual decay channels
- most powerful: combination of channels
  - finer binning
  - complementary sensitivities

With current sensitivity, some bins have to be merged



EFT interpretations of STXS

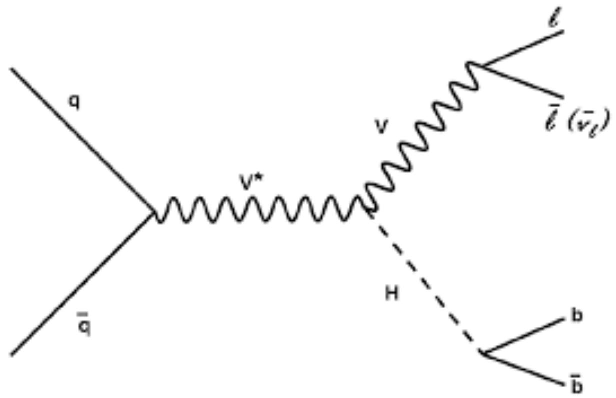
- reparameterization of XS and BR in the fit
- careful with acceptance effects!

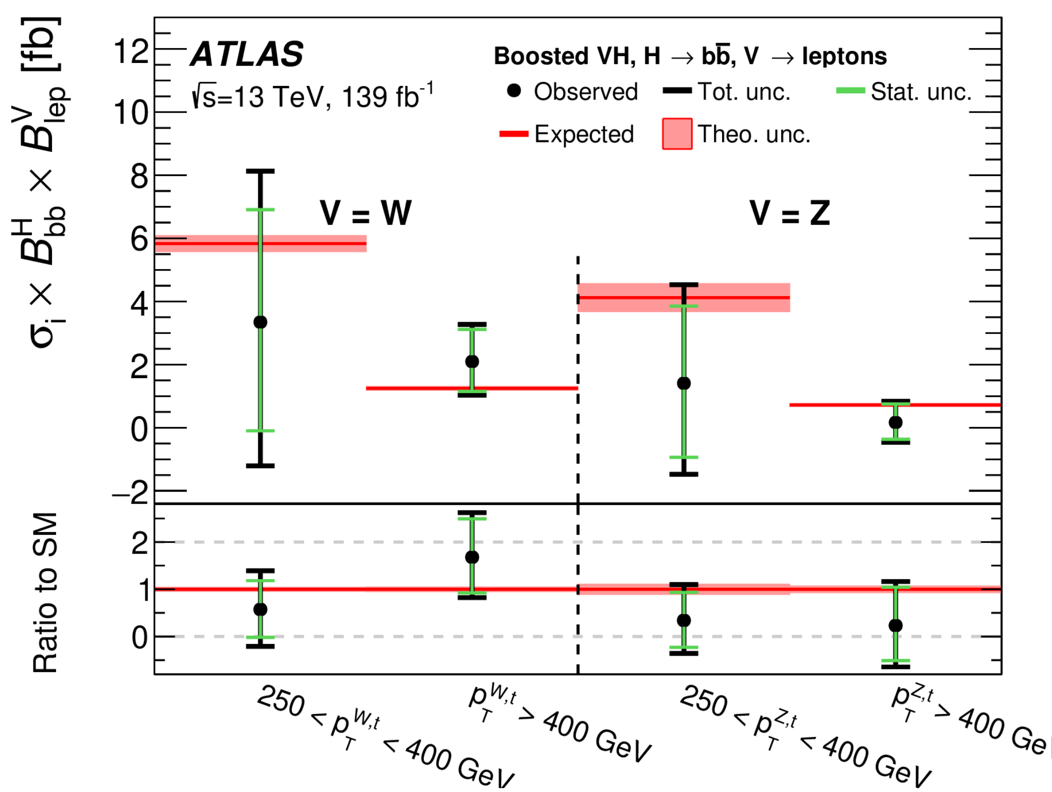
Interference only, pre-Taylor expansion (acceptance not linearized)

$$(\sigma \times B)^{i,H\to X} = (\sigma \times B)^{i,H\to X}_{\mathrm{SM,((N)N)NLO}} \times \left(1 + \frac{\sigma^i_{\mathrm{int,(N)LO}}}{\sigma^i_{\mathrm{SM,(N)LO}}}\right) \times \left(\frac{1 + \frac{\Gamma^{H\to X}_{\mathrm{int}}}{\Gamma^{H\to X}_{\mathrm{SM}}}}{1 + \frac{\Gamma^{H}_{\mathrm{int}}}{\Gamma^{H}_{\mathrm{SM}}}}\right)$$

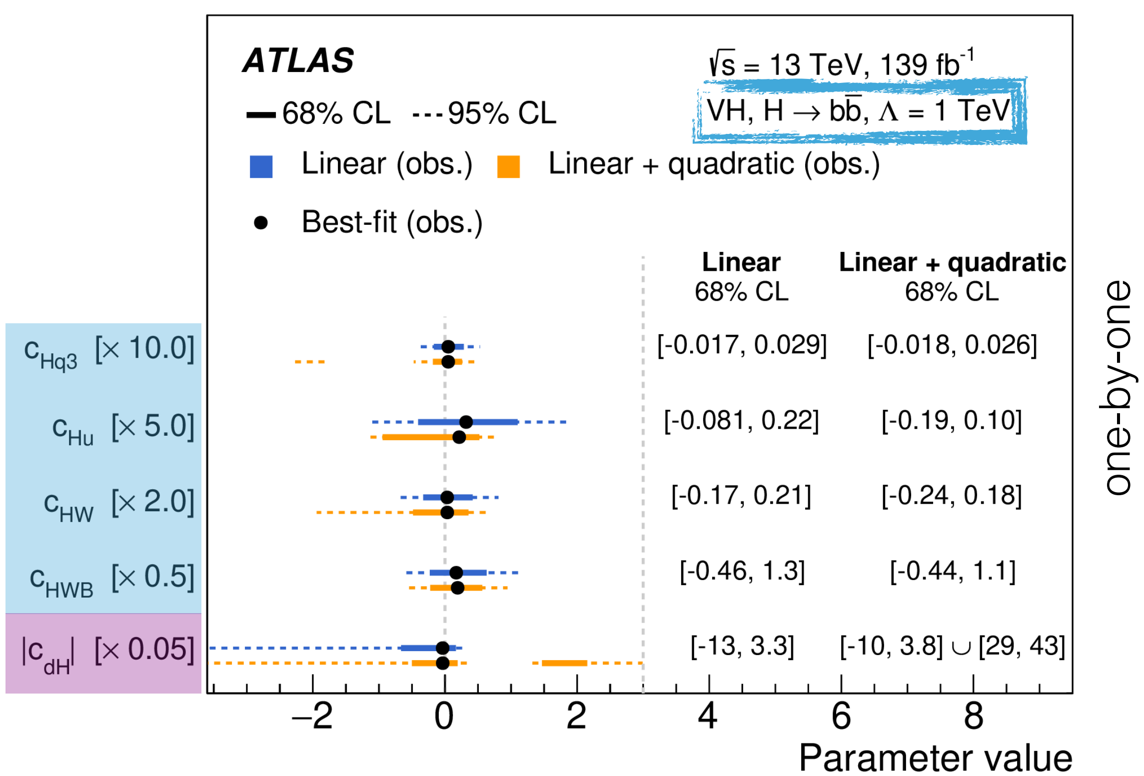
STXS - VH (H → bb)

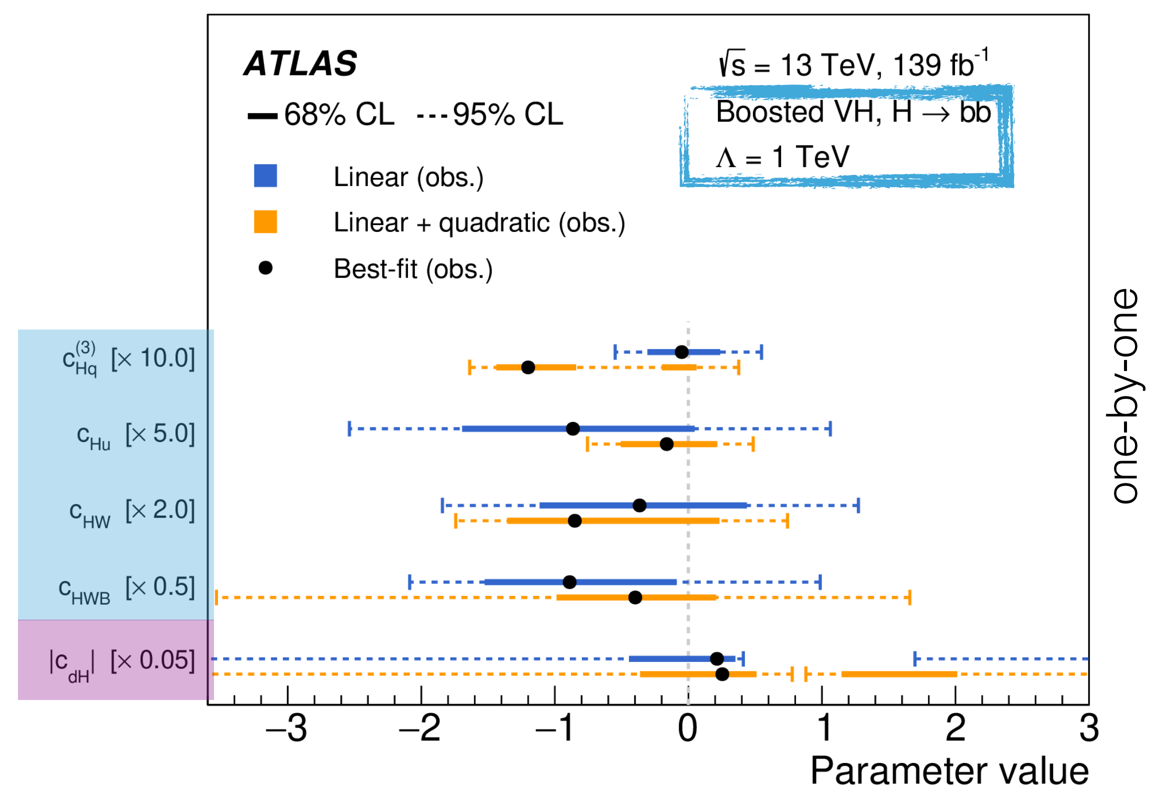
Eur. Phys. J. C 81 (2021) 178, arXiv:2008.02508





- two analyses, depending on the transverse momentum of the Higgs boson (>150, >250 GeV and >250, > 400 GeV)
- constraints of EFT operators in Warsaw basis: modifiers of
  - VH (c^3_{Hq}, c_{HW} , c_{HWB} , c_{Hu})
  - H - down-type quarks vertices ($|c_{dH}|$)
- effect of quadratic term small for "low" p_T





Also simultaneous fit performed in eigenvectors from principal component analysis

Bonus: 2HDM/MSSM interpretations

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Additional Higgs bosons

- can be looked for directly in resonance searches
- can also affect Higgs (125 GeV) couplings/XS * BR
- for constraints/comparisons/combinations between searches and measurements: need benchmark model

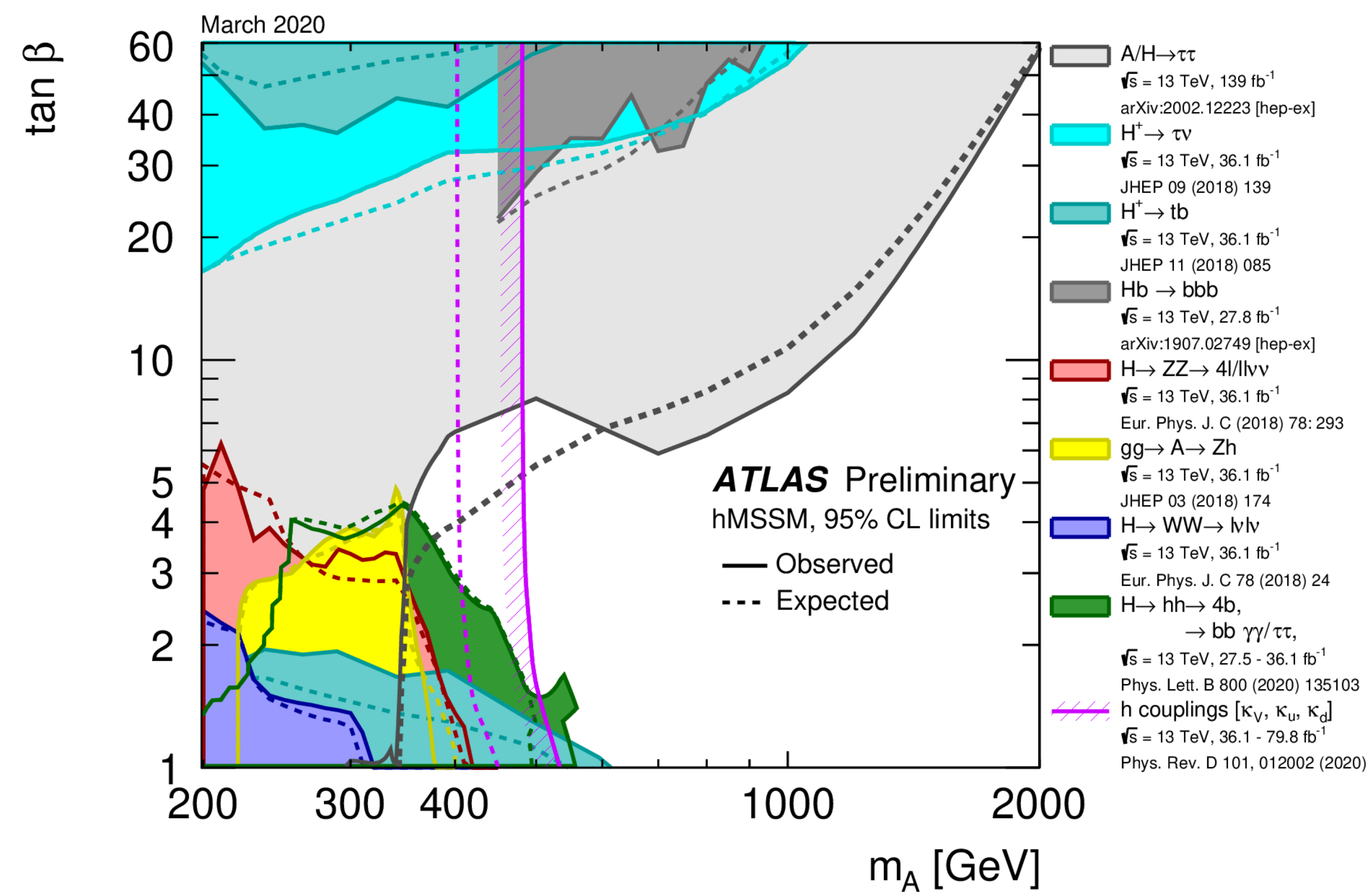
hMSSM:

- two parameters
- limitations for small M_A, or large tan β, or both low M_A and low tan β

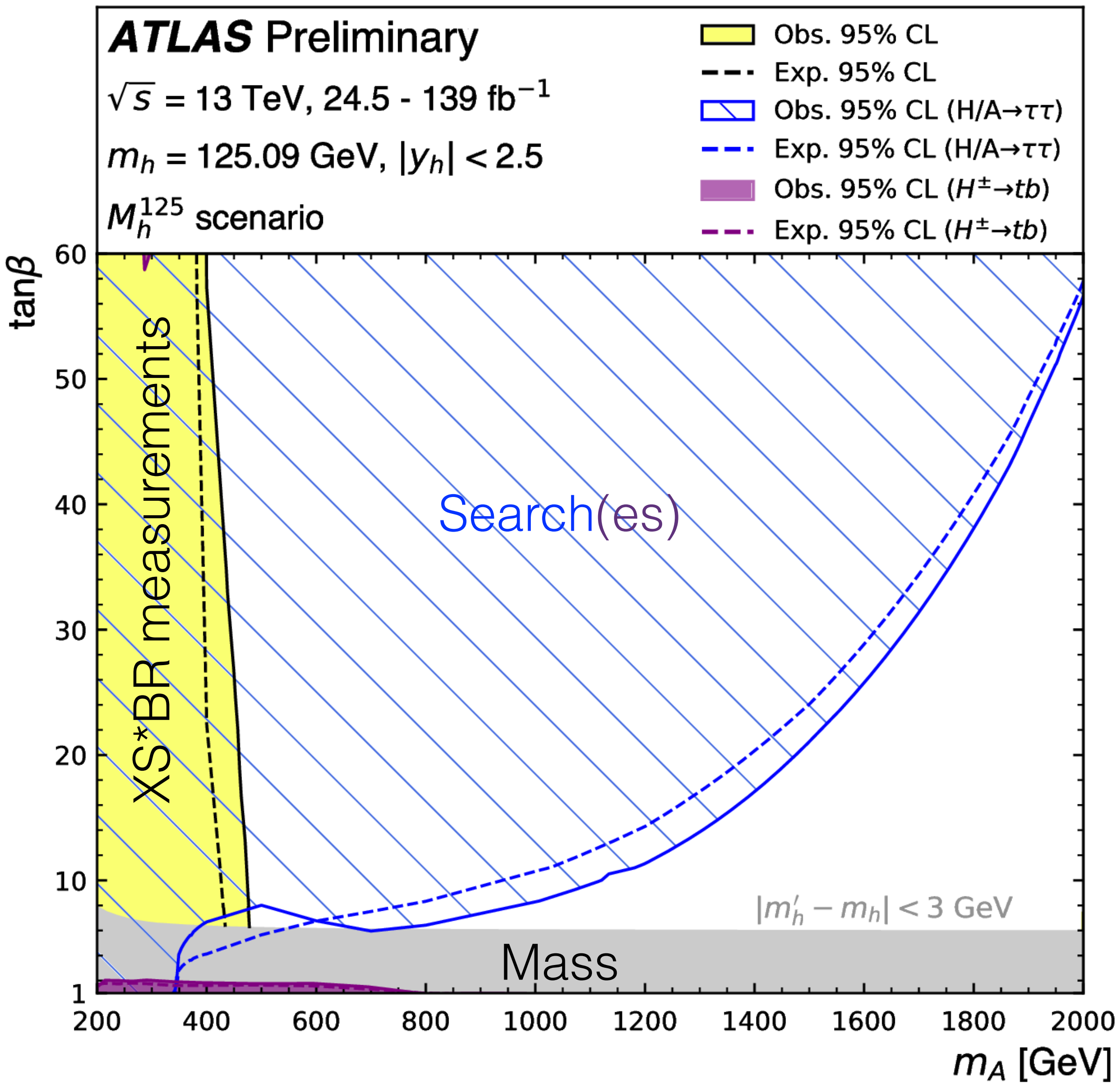
=> more realistic MSSM benchmarks have been developed
(*Eur. Phys. J. C 79 (2019) 617,*
Eur. Phys. J. C 79 (2019) 279)

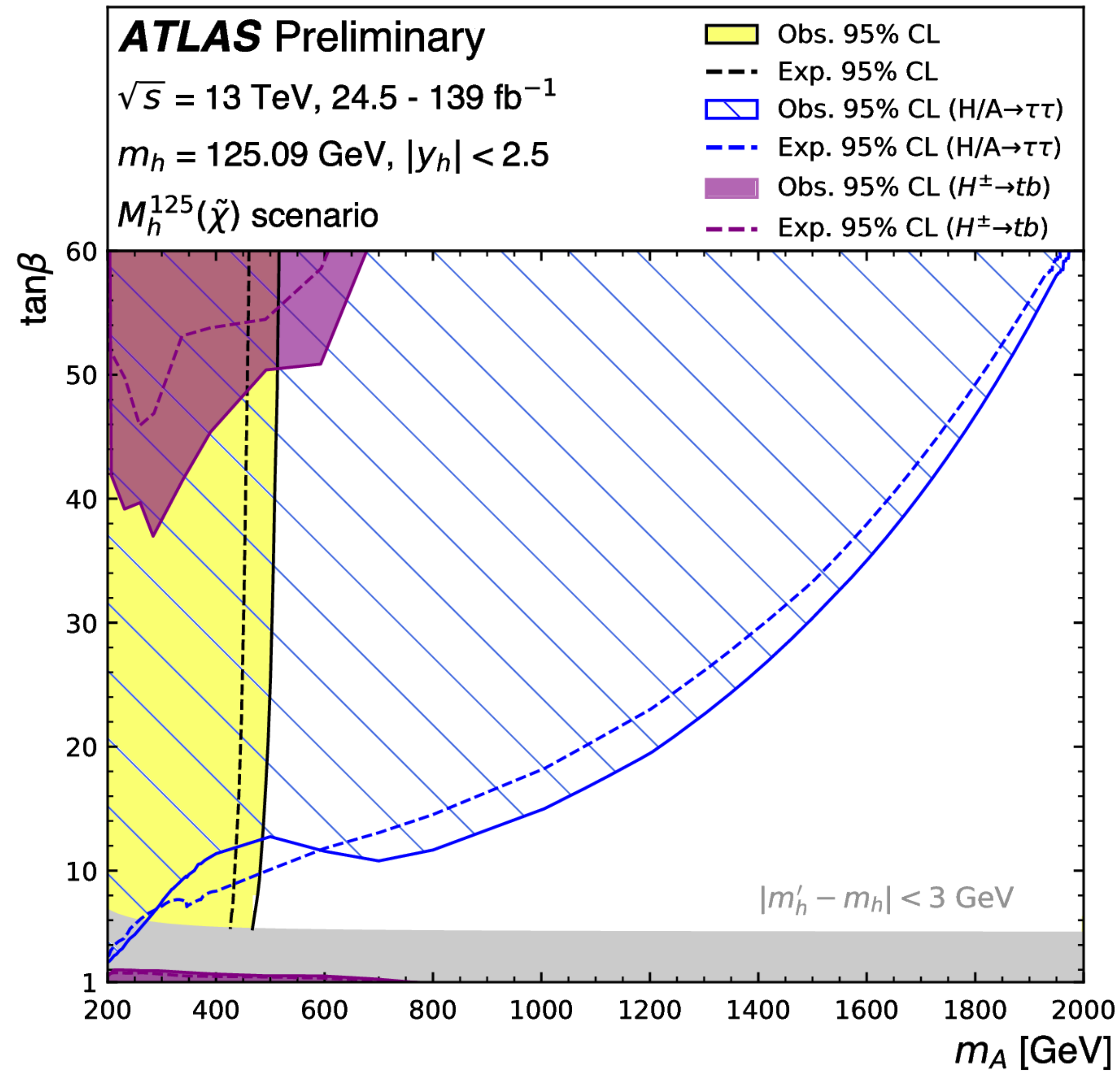
=> also limits set for different 2HDM types

- combination of all available Higgs boson XS * BR measurements
- confront with benchmark predictions



MSSM limits in benchmark models

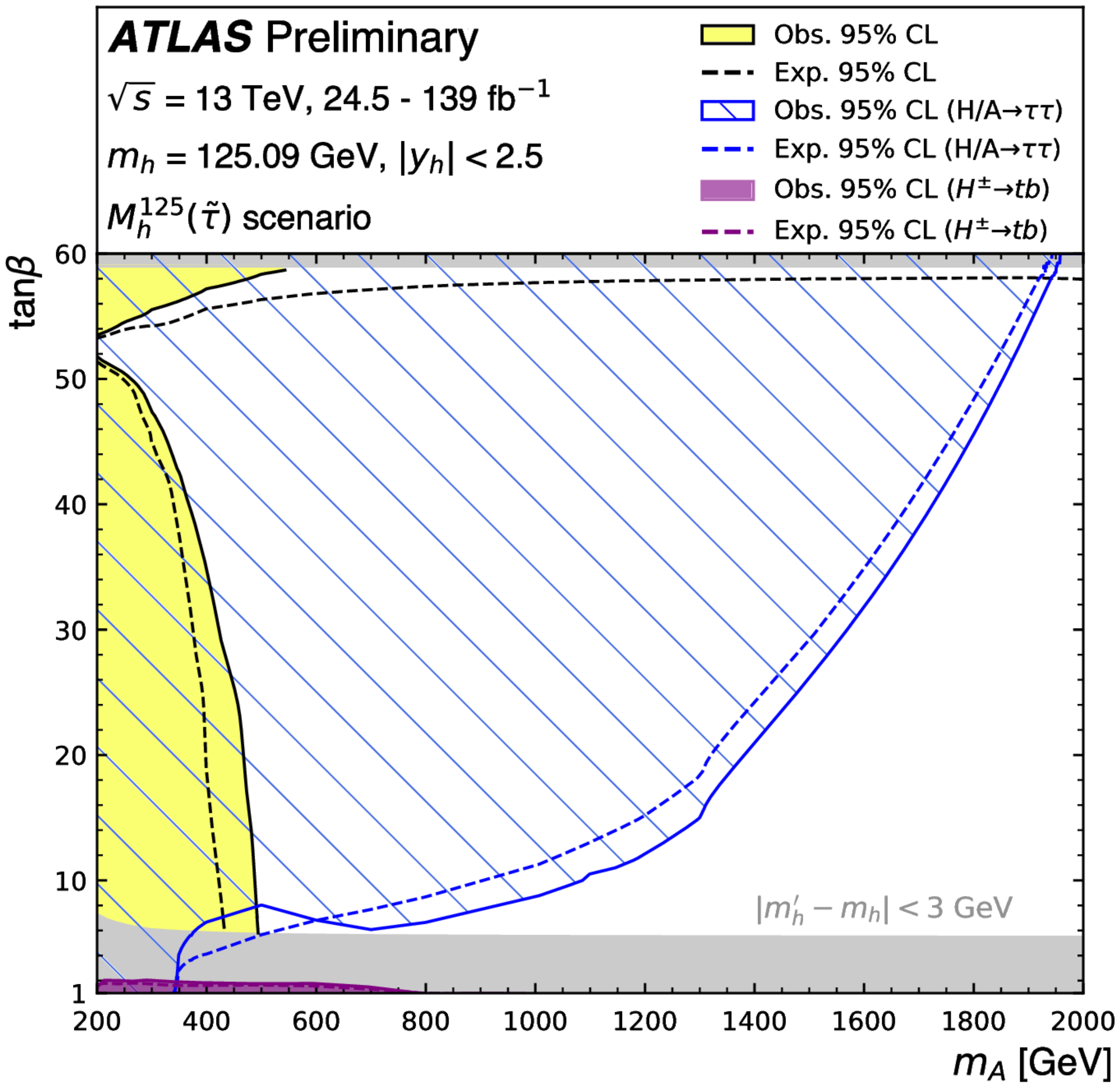


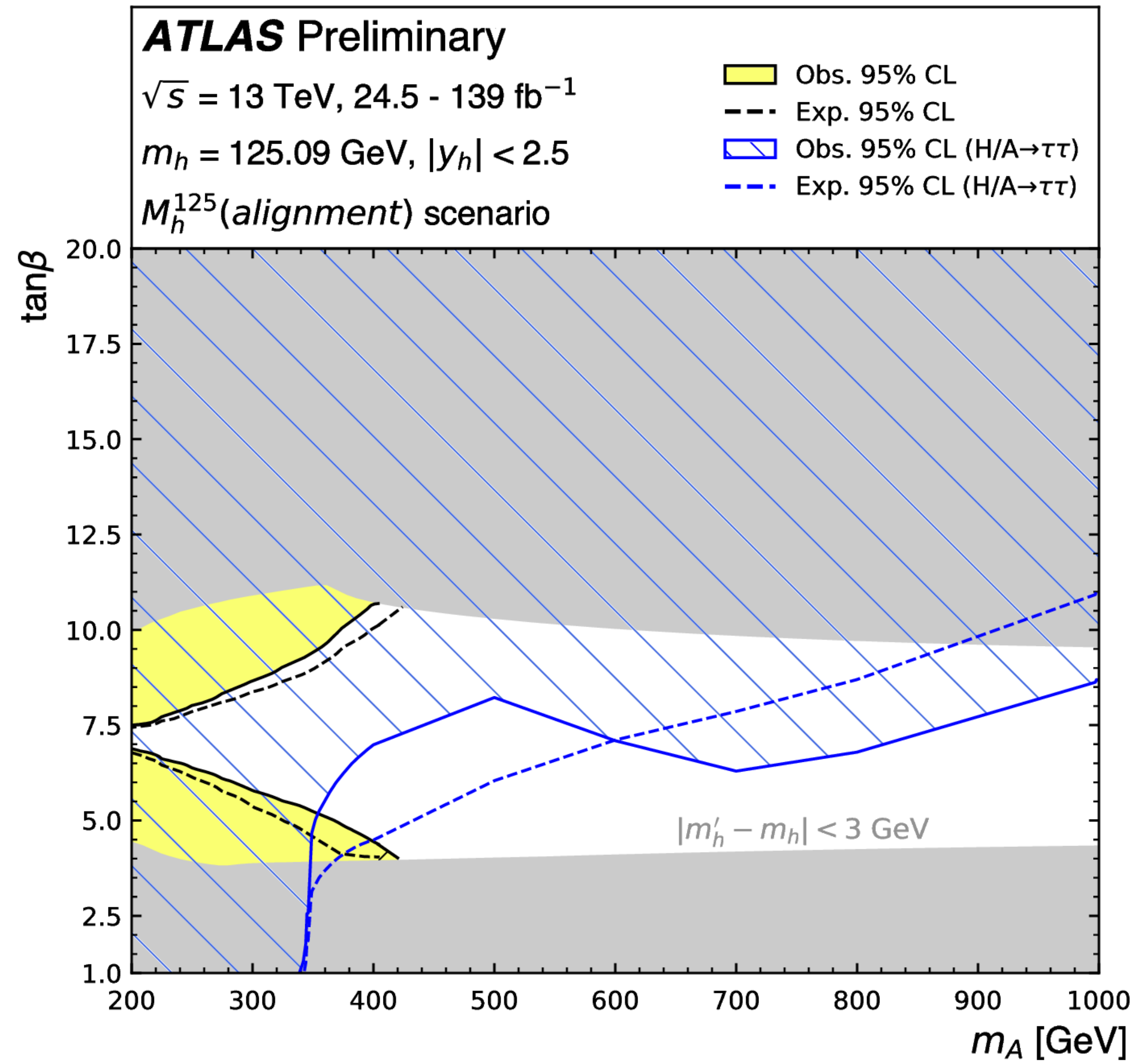


All super-particles very heavy => production and decays of the MSSM Higgs bosons are only mildly affected

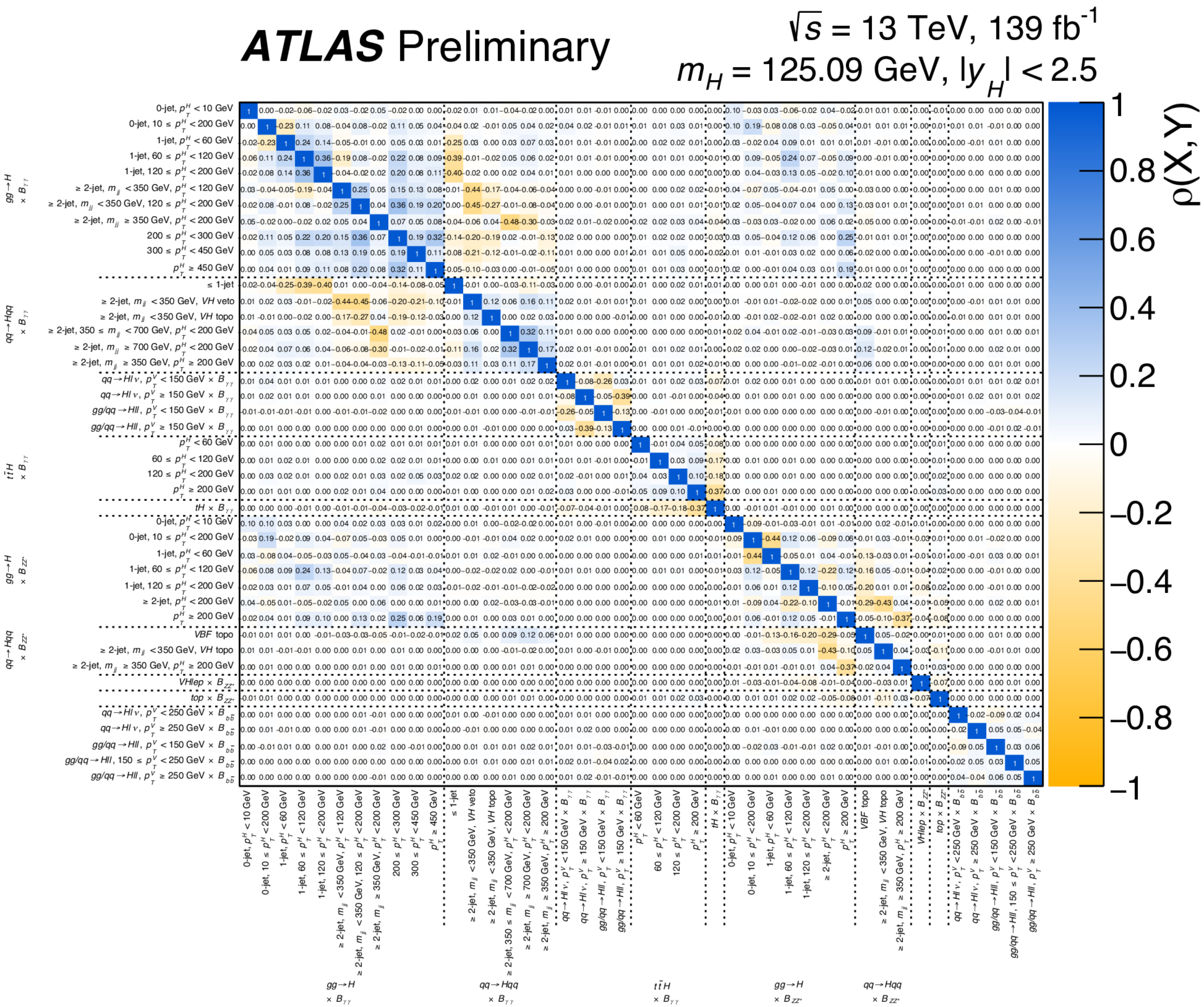
All charginos and neutralinos are relatively light with significant higgsino-gaugino mixing
=> weakening the exclusion bounds from H/A → ττ searches, and from H → **γγ**

More MSSM limits

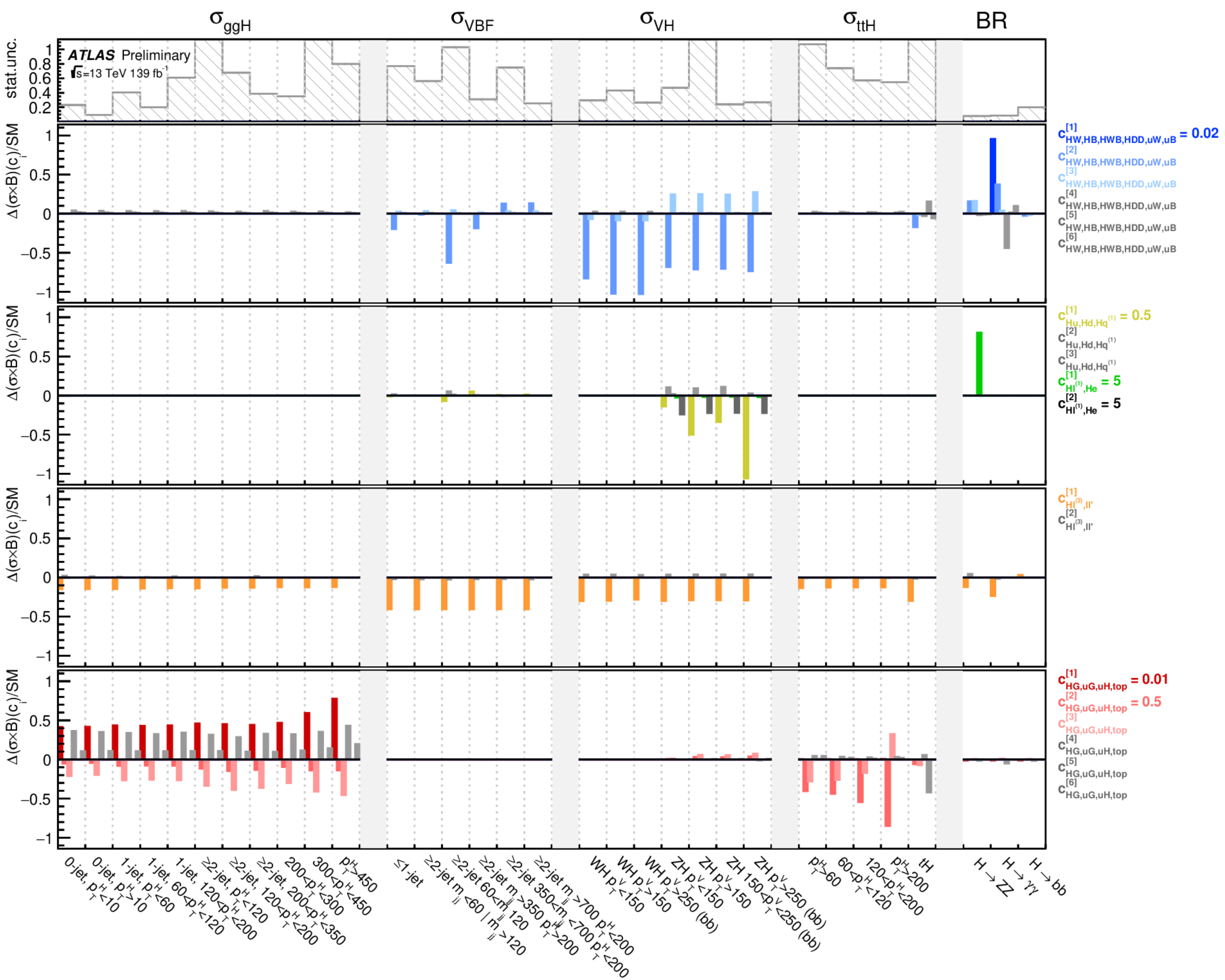




Correlation matrix combined measurement



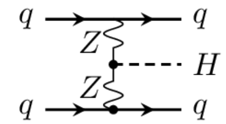
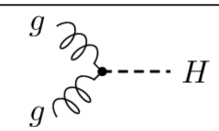
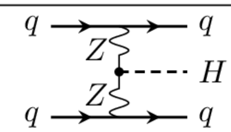
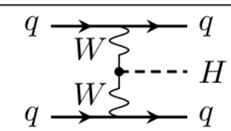
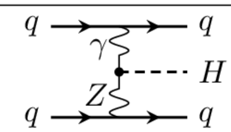
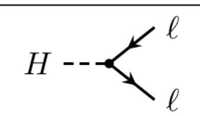
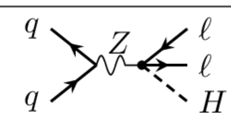
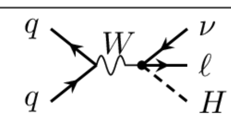
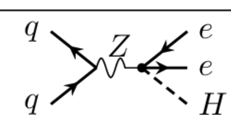
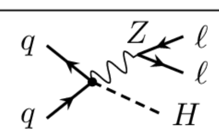
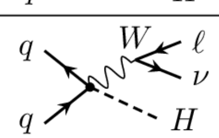
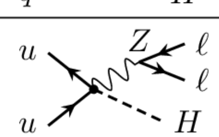
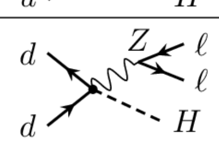
STXS - Effect of rotated operators on XS and BR

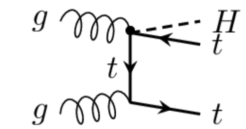
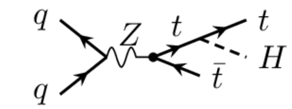
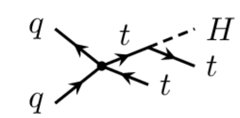
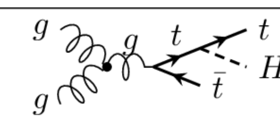


Warsaw basis, operators used in Higgs analyses

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}	$(H^\dagger D^\mu H)^*\,(H^\dagger D_\mu H)$	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	$f^{ABC}G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$

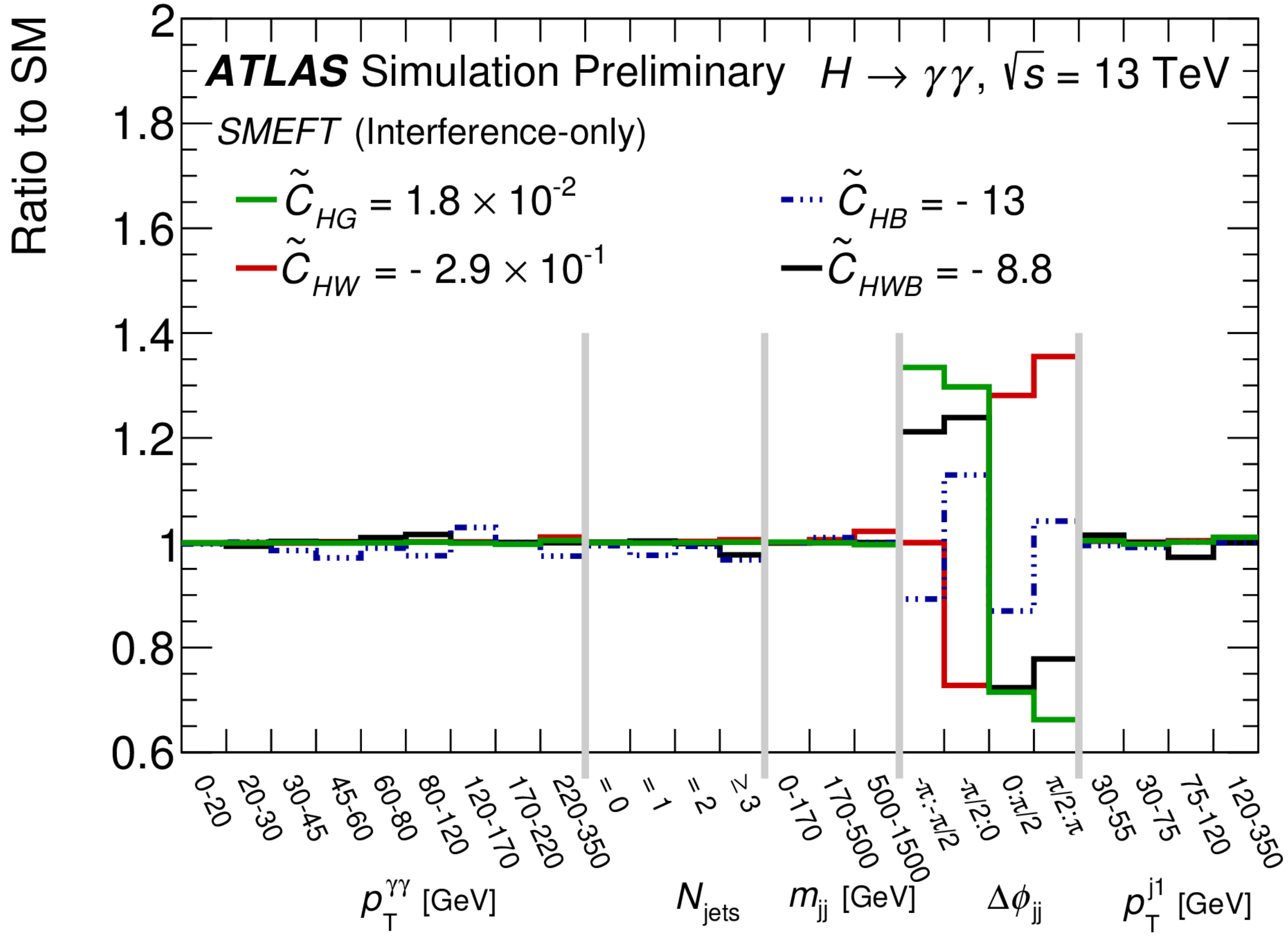
Warsaw basis, some example diagrams

Coefficient	Operator	Example process
c_{HDD}	$(H^\dagger D^\mu H)^* (H^\dagger D_\mu H)$	
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}	$(H^\dagger H)(\bar{l}_p e_r H)$	
$c^{(1)}_{Hl}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)$	
$c^{(3)}_{Hl}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_p \tau^I \gamma^\mu l_r)$	
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}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$	

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	$f^{ABC} G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	

All terms respect the SM U(3)[5] flavour symmetry

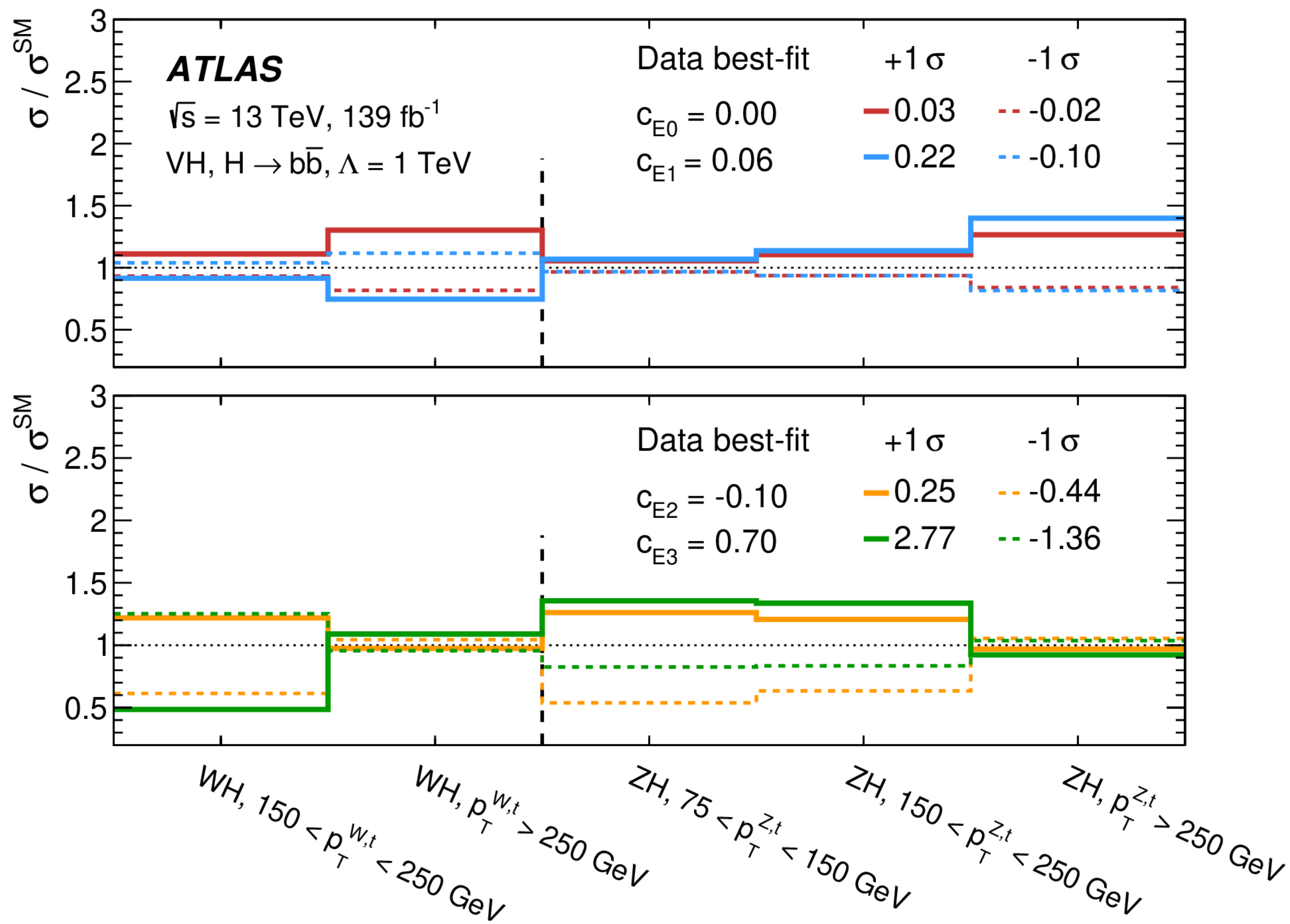
H->yy CP-odd


ATLAS Simulation Preliminary $H \rightarrow \gamma\gamma$, $\sqrt{s}$ = 13 TeV
SMEFT (Interference-only)
$\tilde{C}_{HG} = 1.8 \times 10^{-2}$
$\tilde{C}_{HB} = -13$
$\tilde{C}_{HW} = -2.9 \times 10^{-1}$
$\tilde{C}_{HWB} = -8.8$
Ratio to SM
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0-20
20-30
30-45
45-60
60-80
80-120
120-170
170-220
220-350
= 0
= 1
= 2
≥ 3
0-170
170-500
500-1500
-π:-π/2
-π/2:0
0:π/2
π/2:π
30-55
30-75
75-120
120-350
$p_T^{\gamma\gamma}$ [GeV]
N_{jets}
m_{jj} [GeV]
$\Delta\phi_{jj}$
p_T^{j1} [GeV]

VHbb eigenvector fit

Wilson coefficient	Eigenvalue	Eigenvector
c_{E0}	2000	$0.98 \cdot c_{Hq3}$
c_{E1}	38	$0.85 \cdot c_{Hu} - 0.39 \cdot c_{Hq1} - 0.27 \cdot c_{Hd}$
c_{E2}	8.3	$0.70 \cdot \Delta\mathrm{BR}/\mathrm{BR}_{\mathrm{SM}} + 0.62 \cdot c_{HW}$
c_{E3}	0.2	$0.74 \cdot c_{HWB} + 0.53 \cdot c_{Hq1} - 0.32 \cdot c_{HW}$
c_{E4}	$6.4 \cdot 10^{-3}$	$0.65 \cdot c_{HW} - 0.60 \cdot \Delta\mathrm{BR}/\mathrm{BR}_{\mathrm{SM}} + 0.35 \cdot c_{Hq1}$

BR separately (1 linear parameter)
All contributions with coefficients below 0.2 are omitted



VHbb operators

Table 14: Wilson coefficients c_i and corresponding dimension-6 SMEFT operators Q_i, to which this analysis sensitive, in the Warsaw formulation [126].

Wilson coefficient	Operator	Impacted vertex Production	Decay
c_{HWB}	$Q_{HWB} = H^\dagger \tau^I H W^I_{\mu\nu} B^{\mu\nu}$	HZZ	
c_{HW}	$Q_{HW} = H^\dagger H W^I_{\mu\nu} W^{\mu\nu}_I$	HZZ, HWW	
$c^{(3)}_{Hq}$	$Q^{(3)}_{Hq} = (H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q}_p \tau^I \gamma^\mu q_r)$	$qqZH, qq'WH$	
$c^{(1)}_{Hq}$	$Q^{(1)}_{Hq} = (H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p \gamma^\mu q_r)$	$qqZH$	
c_{Hu}	$Q_{Hu} = (H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$	$qqZH$	
c_{Hd}	$Q_{Hd} = (H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$	$qqZH$	
c_{dH}	$Q_{dH} = (H^\dagger H)(\bar{q} d H)$		Hbb

- Expected ggZH fixed to the SM within uncertainties
- No acceptance effects included, checked that they were at most 10% (20% for boosted analysis)
- Limits were produced using the full likelihood and using only the STXS measurement central values and covariance matrix, agreement within 10-20%, 30% for weakest constraints
- 5 STXS regions
- Also 2D constraints produced

SILH basis

$$\Delta\mathcal{L}^{(6)} = \boxed{\Delta\mathcal{L}_{SILH}} + \Delta\mathcal{L}_{cc} + \Delta\mathcal{L}_{dipole} + \Delta\mathcal{L}_{V} + +\Delta\mathcal{L}_{4\psi}$$

16 operators

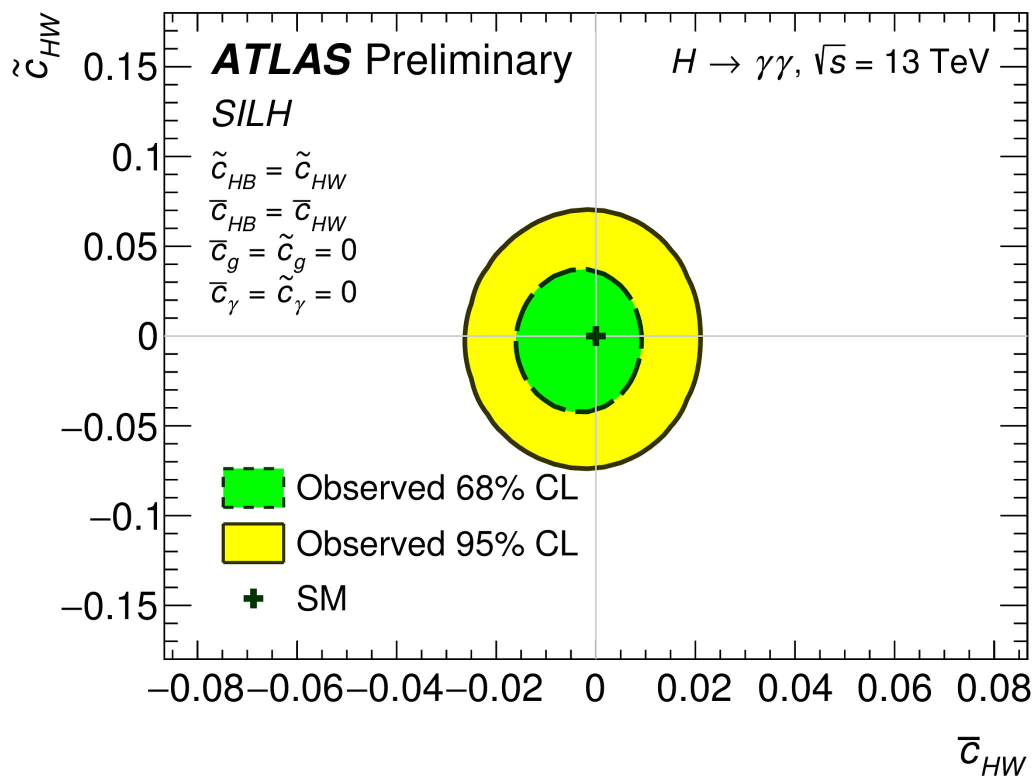
(12 CP even, 4 CP odd)

SILH operators

Giudice, Grojean, Pomarol, Rattazzi JHEP 0706 (2007) 045

$$\begin{aligned}
\Delta\mathcal{L}_{SILH} = & \frac{\bar{c}_H}{2v^2}\,\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3 \\
& + \left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right) \\
& + \frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right) \\
& + \frac{i\bar{c}_{HW}\,g}{m_W^2}\left(D^\mu H\right)^\dagger \sigma^i \left(D^\nu H\right) W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}\left(D^\mu H\right)^\dagger\left(D^\nu H\right) B_{\mu\nu} \\
& + \frac{\bar{c}_\gamma\,g'^2}{m_W^2}\,H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu} G^{a\mu\nu} \\
& + \frac{i\tilde{c}_{HW}\,g}{m_W^2}\left(D^\mu H\right)^\dagger \sigma^i \left(D^\nu H\right) \tilde{W}^i_{\mu\nu} + \frac{i\tilde{c}_{HB}\,g'}{m_W^2}\left(D^\mu H\right)^\dagger\left(D^\nu H\right) \tilde{B}_{\mu\nu} \\
& + \frac{\tilde{c}_\gamma\,g'^2}{m_W^2}\,H^\dagger H B_{\mu\nu} \tilde{B}^{\mu\nu} + \frac{\tilde{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu} \tilde{G}^{a\mu\nu}
\end{aligned}$$

SILH basis, example limits H->yy diff XS

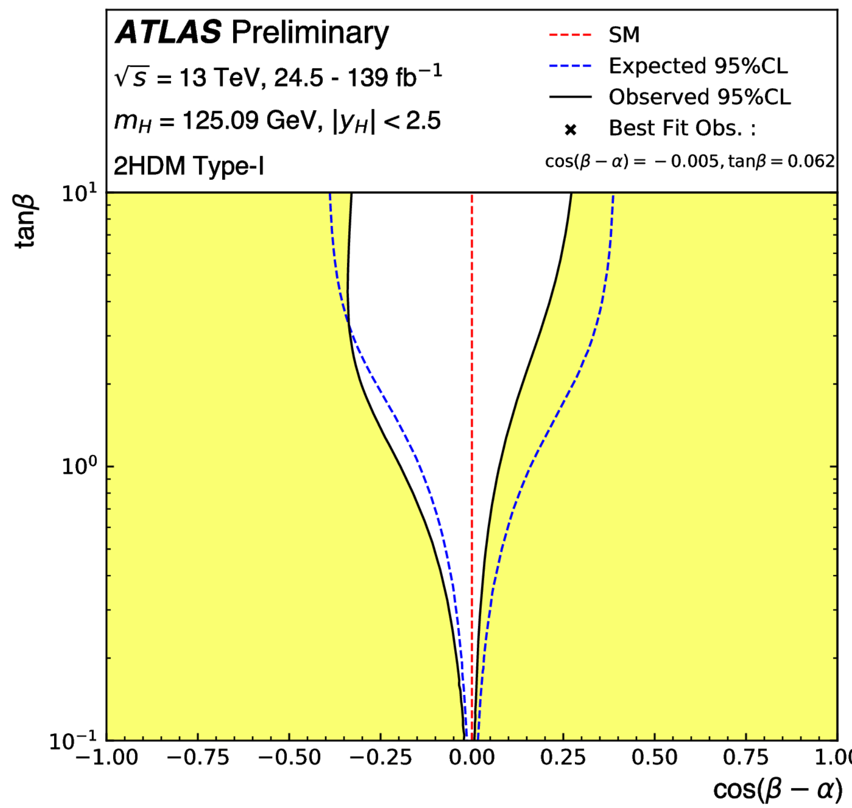


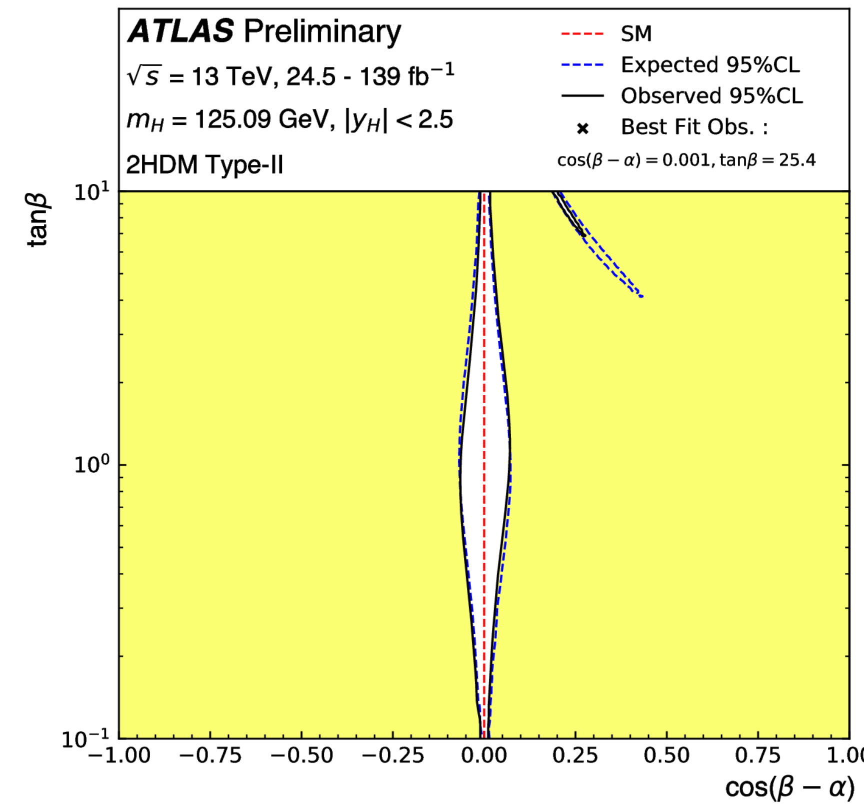
Couplings to vector bosons

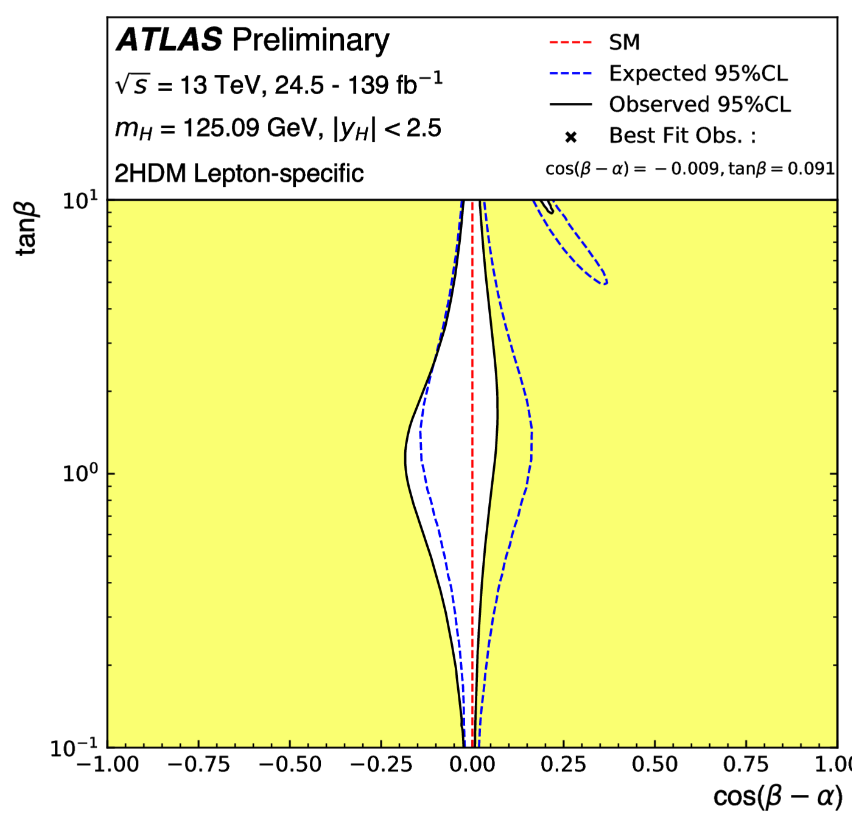
SILH basis of the Higgs effective Lagrangian

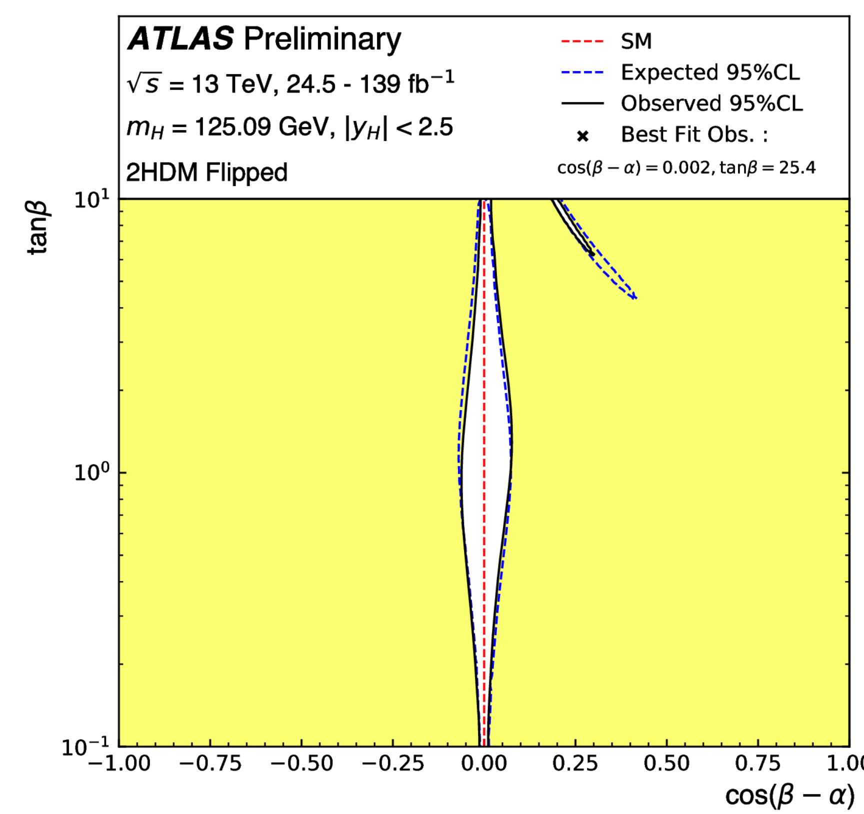
Coefficient	Observed 95% CL limit	Expected 95% CL limit
$\bar{c}_g$	$[-0.26, 0.26] \times 10^{-4}$	$[-0.25, 0.25] \cup [-4.7, -4.3] \times 10^{-4}$
$\tilde{c}_g$	$[-1.3, 1.1] \times 10^{-4}$	$[-1.1, 1.1] \times 10^{-4}$
$\bar{c}_{HW}$	$[-2.5, 2.2] \times 10^{-2}$	$[-3.0, 3.0] \times 10^{-2}$
$\tilde{c}_{HW}$	$[-6.5, 6.3] \times 10^{-2}$	$[-7.0, 7.0] \times 10^{-2}$
$\bar{c}_\gamma$	$[-1.1, 1.1] \times 10^{-4}$	$[-1.0, 1.2] \times 10^{-4}$
$\tilde{c}_\gamma$	$[-2.8, 4.3] \times 10^{-4}$	$[-2.9, 3.8] \times 10^{-4}$

2HDM limits


ATLAS Preliminary
√s = 13 TeV, 24.5 - 139 fb⁻¹
m_H = 125.09 GeV, |y_H| < 2.5
2HDM Type-I
SM
Expected 95%CL
Observed 95%CL
Best Fit Obs. :
cos(β − α) = − 0.005, tanβ = 0.062
tanβ
cos(β − α)


ATLAS Preliminary
√s = 13 TeV, 24.5 - 139 fb⁻¹
m_H = 125.09 GeV, |y_H| < 2.5
2HDM Type-II
SM
Expected 95%CL
Observed 95%CL
Best Fit Obs. :
cos(β − α) = 0.001, tanβ = 25.4
tanβ
cos(β − α)


ATLAS Preliminary
√s = 13 TeV, 24.5 - 139 fb⁻¹
m_H = 125.09 GeV, |y_H| < 2.5
2HDM Lepton-specific
SM
Expected 95%CL
Observed 95%CL
Best Fit Obs. :
cos(β − α) = − 0.009, tanβ = 0.091
tanβ
cos(β − α)


ATLAS Preliminary
√s = 13 TeV, 24.5 - 139 fb⁻¹
m_H = 125.09 GeV, |y_H| < 2.5
2HDM Flipped
SM
Expected 95%CL
Observed 95%CL
Best Fit Obs. :
cos(β − α) = 0.002, tanβ = 25.4
tanβ
cos(β − α)