EFT with ATLAS

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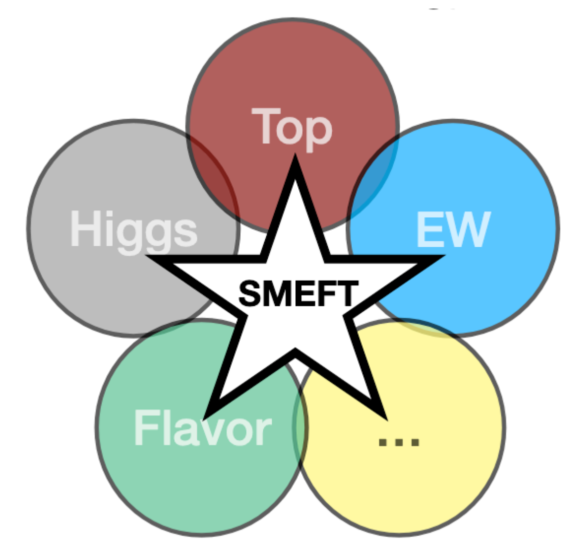
Assemblée Générale Enigmass - 28/10/2021

Overview

The LHC has not found any evidence of New Physics.

- Direct searches for SUSY or exotics continue, but the focus on indirect exploration is increasing…
- Increasing number of Effective Field Theory (EFT) measurements and reinterpretations in ATLAS:
  - EW : reinterpretation of differential fiducial XS;
  - Top : $t\bar{t}$ differential cross-sections, Charge asymmetries, ttV, ecc..
  - Higgs: STXS (Simplified template cross section)-based interpretations in all main decays modes (H→γγ, 4l, WW*, bb, ττ) and combination; dedicated analyses for CP.
- Input observables: asymmetries, angles, pT , mass…
- Interpretation in context of EFT complementing (or superseding) other interpretations -> application on a variety of analyses.
  - κ-framework (Higgs);
  - anomalous couplings (SM, Top);
  - polarisation measurements (SM, Top).
- EFT results interpret unfolded spectrum (reinterpretation - indirect) or measure coefficients with the primary likelihood (reparameterisation - direct).



Theoretical framework

- An EFT approach can be used to set **model-independent constraints** on BSM physics, assuming that the scale of new physics is high enough to decouple from the SM.
- Constrain EFT coefficients ➙ constrain large classes of UV theories.
- Consider an EFT generalisation of the SM, SMEFT (SM Higgs doublet is present in the EFT construction); it describes BSM effects @LHC in scenarios where BSM is out of collider reach.
- In SMEFT, the effects of BSM dynamics at high energies $\Lambda \gg$ v, can be parametrised at low energies, $E \ll \Lambda$, in terms of higher-dimensional operators built up from the Standard Model fields, respecting its symmetries such as gauge invariance and using the same fields:

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

complete set of operators of mass-dimensions d = 6 and d = 8

SM Lagrangian

Wilson coefficients

- only CP-even dimension-6 operators are considered (dim-5/7 operators -> violate lepton and/or baryon number conservation);
- the Warsaw basis, which provides a complete set of independent operators allowed by the SM gauge symmetries, is used; a value of $\Lambda = 1$ TeV is assumed.
- Flavour symmetry (U(3)5) assumed to reduce the number of parameters - 25/85 (CP odd - all)

(Selection of) ATLAS recent results

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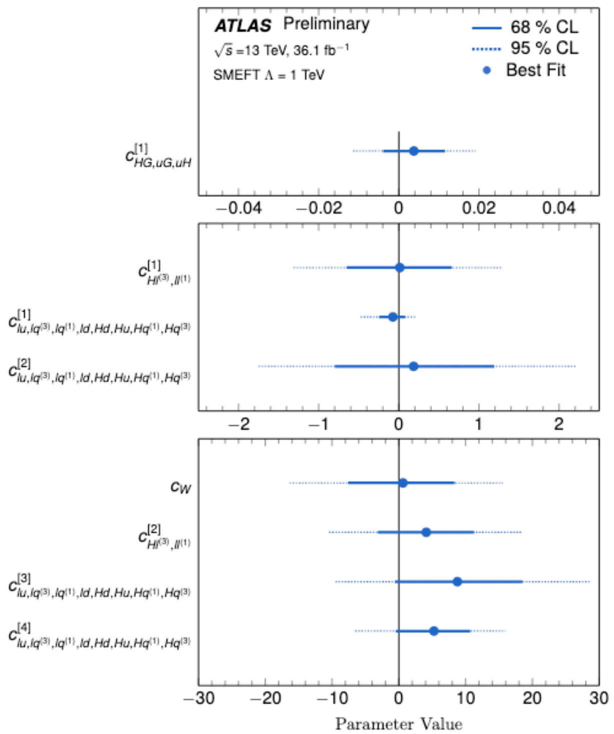

HWW+WW

- Combination of two Hbb analyses: resolved ptV > 75 GeV +two separate jets boosted ptV>250 GeV + one large-R jet

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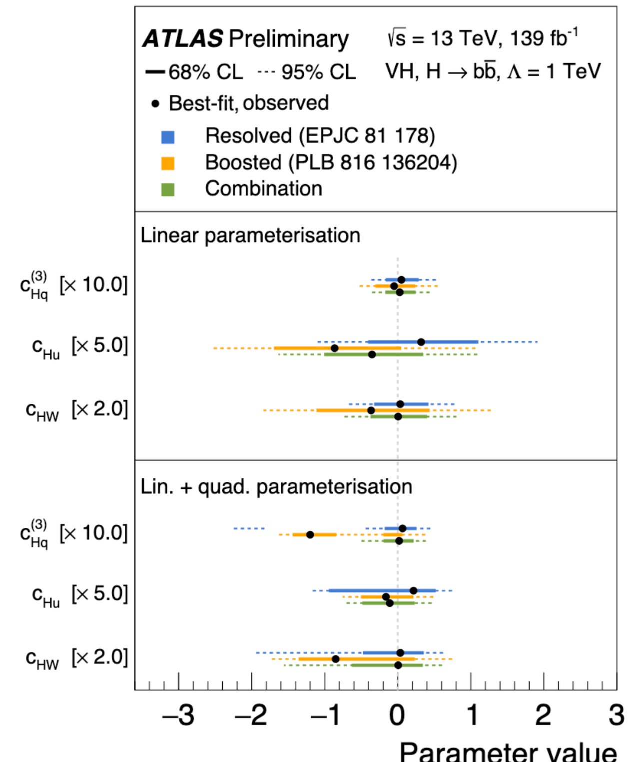
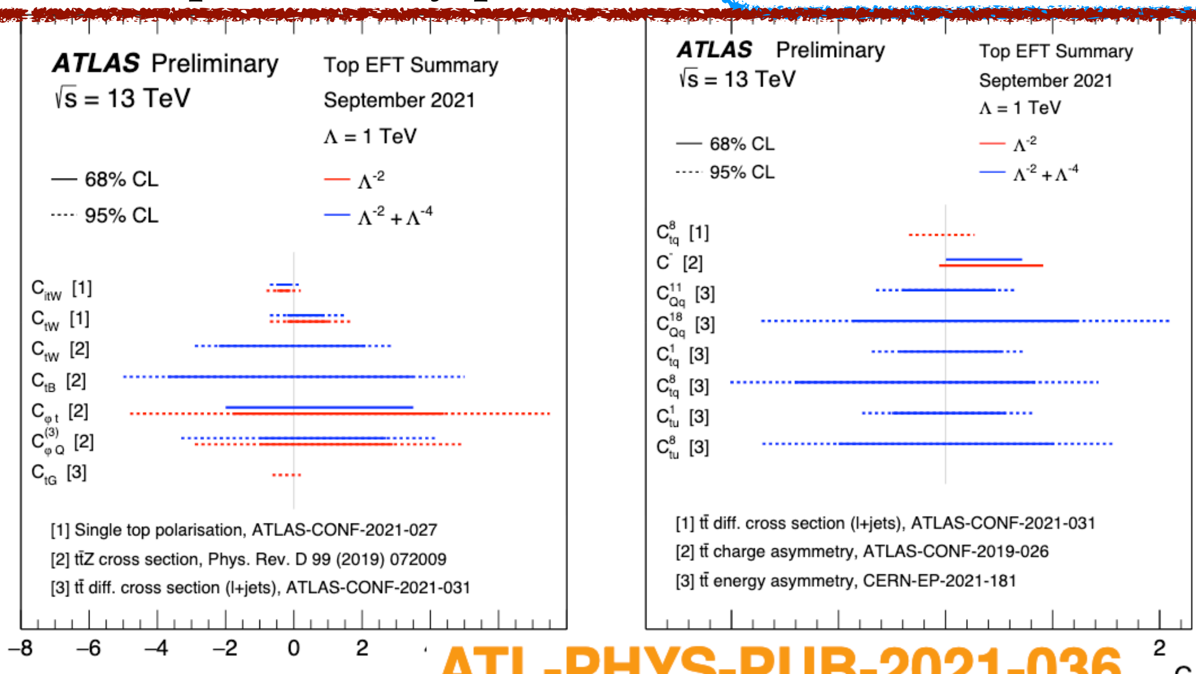


Top summary plots



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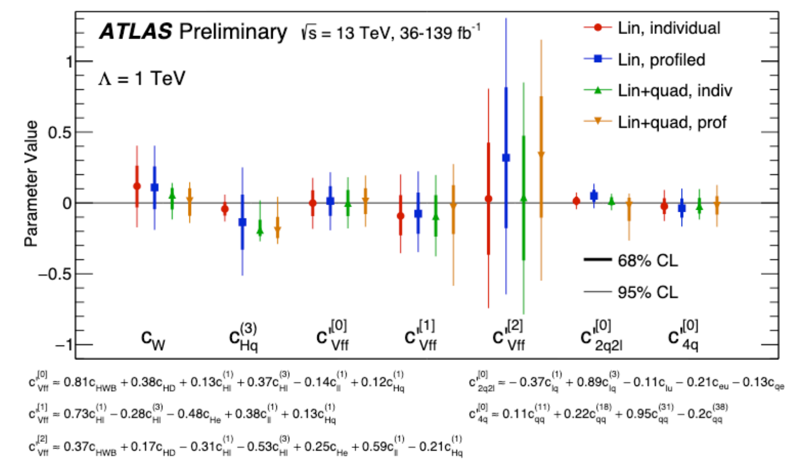
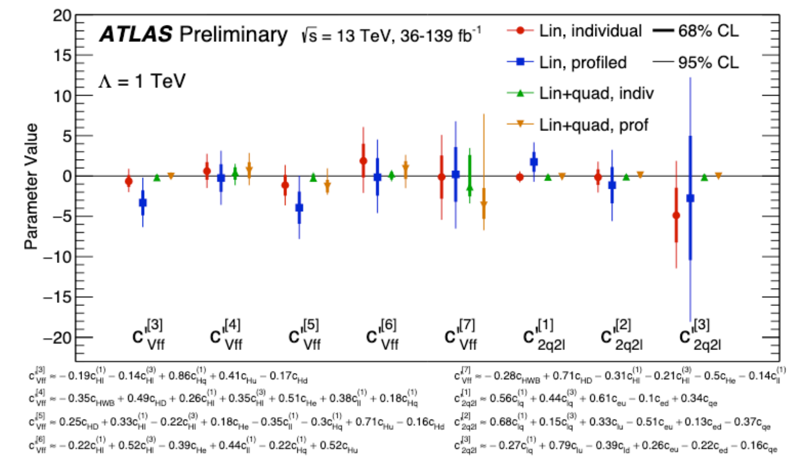
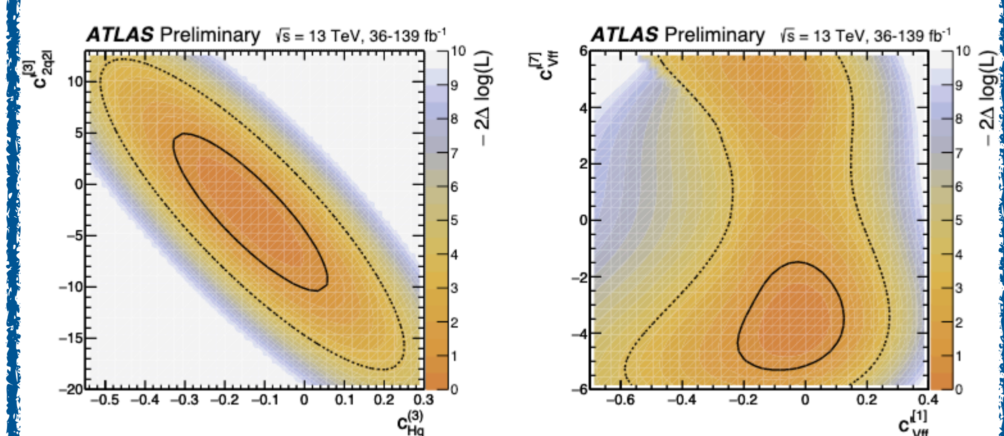




- Four EW SM analyses WW,WZ ,4l and Z +2j
- Simultaneous fit of 15 coefficients.

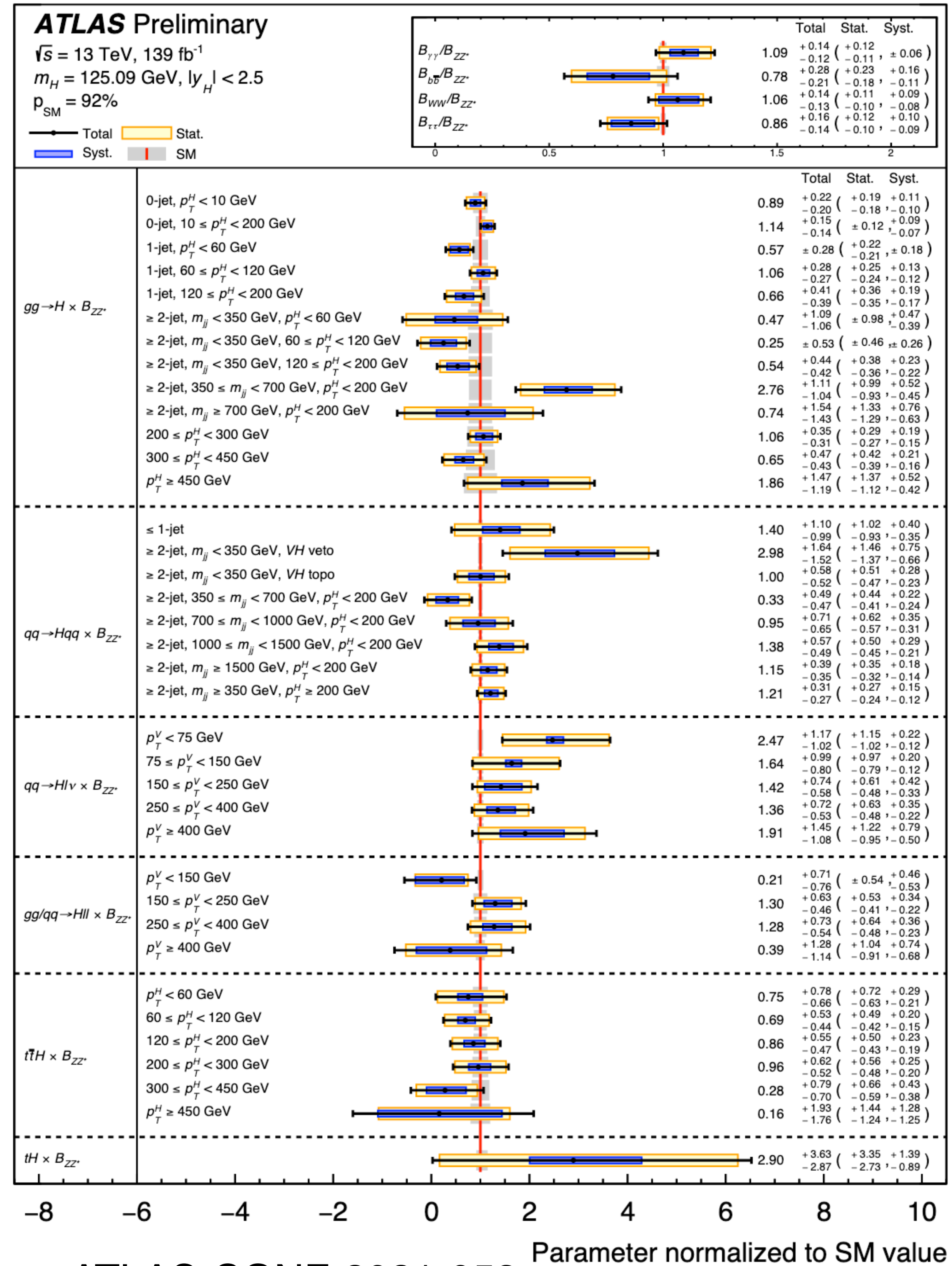


LAPP

STXS measurements

- Dedicated particle-level (truth) regions of the production phase space (approximately fiducial on production side), inclusive for all Higgs decays.
- Compromise between differential distributions and experimental sensitivity; designed to minimise theory uncertainty and provide BSM sensitivity.
- Measurements available for all main decay modes (γγ, 4l, 2l2ν, bb, ττ).
- Measured signal strength for each STXS category used in EFT analysis to extract constraints on (combinations of) Wilson coefficients.

Decay channel		Target Production 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
$H \to WW^*$	**Updated**	ggF, VBF	139
$H \to \tau\tau$	**Updated**	ggF, VBF, WH, ZH, $t\bar{t}H$	139
$H \to b\bar{b}$	**NEW**	WH, ZH	139
	Updated	VBF	126
	Updated	$t\bar{t}H$	139



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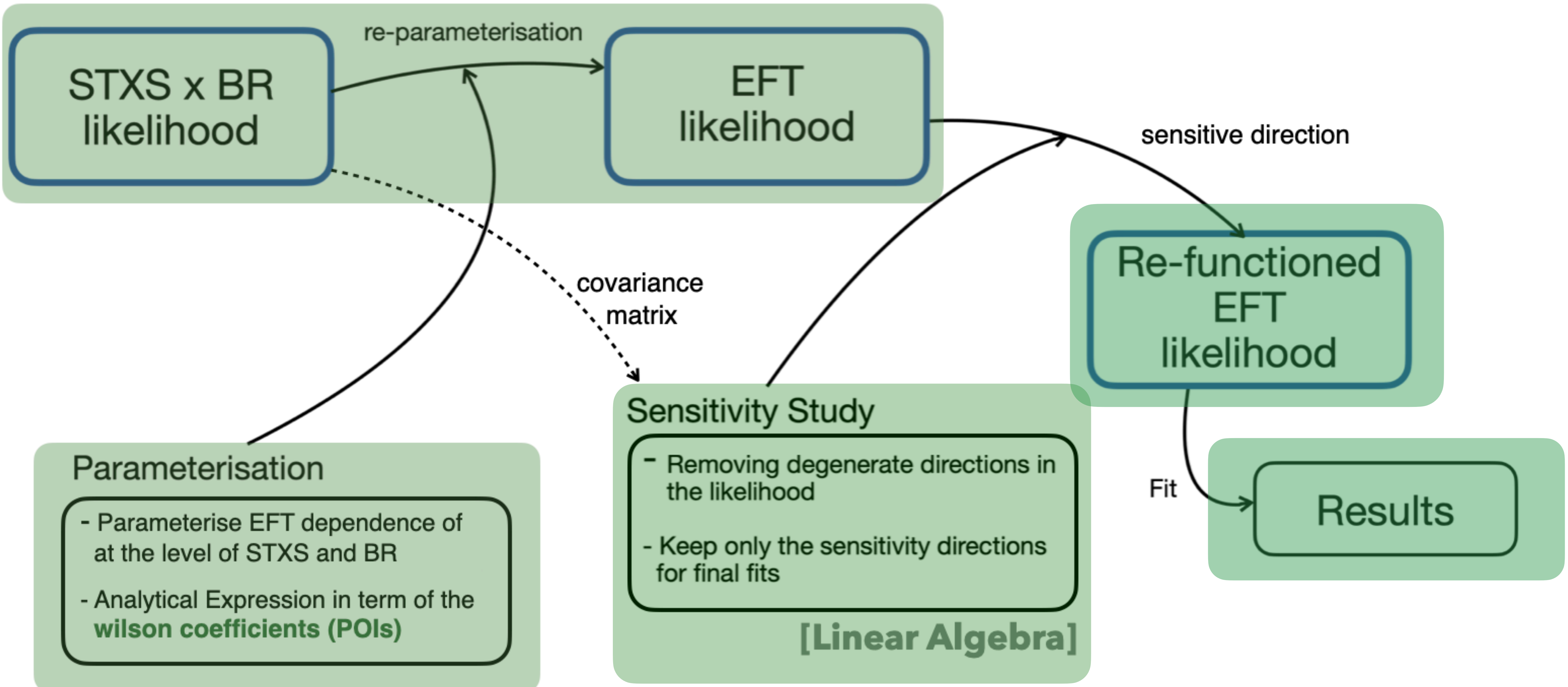
ATLAS EXPERIMENT

EFT workflow

Focus on the methodology used in the Higgs combination than can/is used also in other combinations.

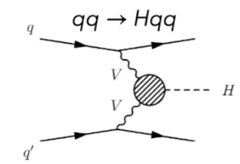


EFT workflow - 1

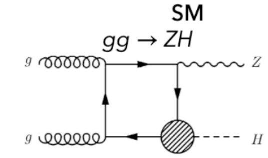
STXS x BR likelihood

re-parameterisation

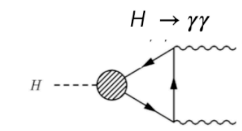
$$\sigma \propto |\mathcal{M}_{SMEFT}|^2 = |\mathcal{M}_{SM} + \textstyle\sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i|^2 = \underbrace{\boxed{|\mathcal{M}_{SM}|^2}}_{\text{SM}} + \underbrace{\boxed{\sum_i \frac{c_i}{\Lambda^2}\mathrm{Re}(|\mathcal{M}_{SM}.(\mathcal{O}_i)^*|)}}_{\text{Dim-6 x SM (linear)}} + \underbrace{\boxed{\sum_{i,j} \frac{c_i.c_j}{\Lambda^4}|\mathcal{O}_j(\mathcal{O}_i)^*|}}_{\text{Dim-6 + missing Dim-8 x SM (quadratic)}}$$



SMEFTsim for LO EFT predictions for production, decay widths



SMEFTatNLO to resolve important loop contributions (ggZH, ggH)



Analytic prediction at NLO EW for $H \to \gamma\gamma$ decay width

covariance matrix

STXS X BR covariance matrix

Parameterisation

- Parameterise EFT dependence of at the level of STXS and BR
- Analytical Expression in term of the **wilson coefficients (POIs)**

SMEFTsim v3.0

SMEFT@NLO

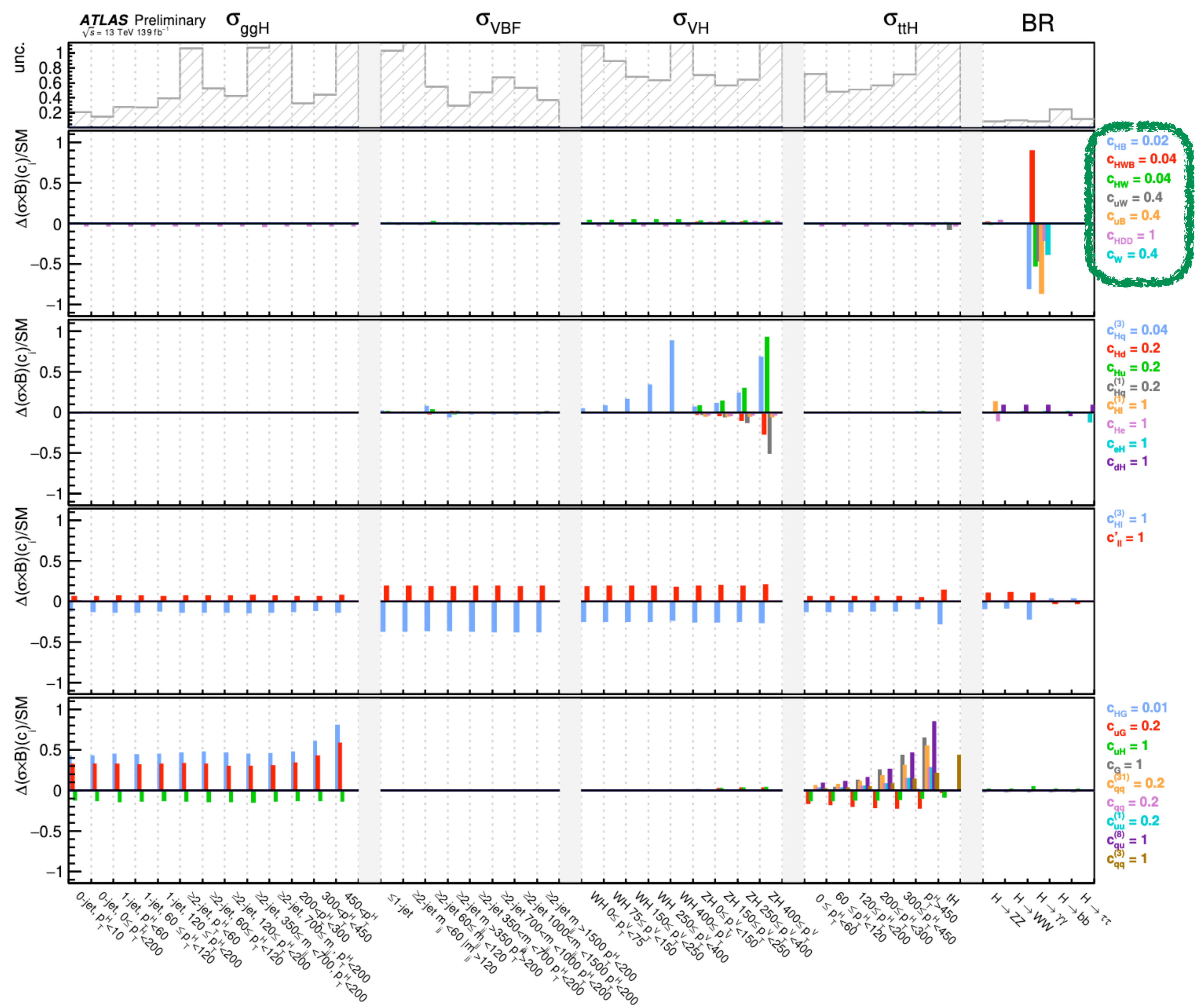
NLO QCD

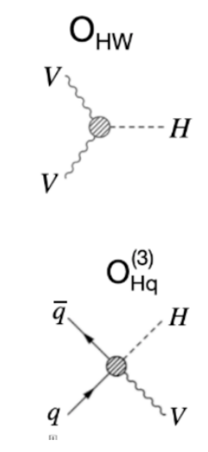
Rivet code (public) implementing the classification of a MC event into STXS bins

STXS Rivet

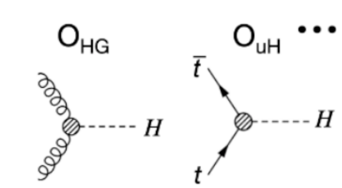
Impact of SMEFT operators on STXS

- Impact of each Wilson coefficient in the different STXS bins or partial widths.
- The impact of most Wilson coefficients is rescaled to fit in the plot.
- Insufficient kinematic information to probe simultaneously 26 parameters!
- Principle Component Analysis in parameter groups to identify sensitive directions.
- EFT parameterisation is affected by analysis level selections used to reconstruct SM Higgs.
- Acceptance effects are included for HWW and HZZ channels.





Modification to Fermi constant (GF)



ATLAS-CONF-2021-053

Sensitivity studies

- Principal Component Analysis to reduce the dimensionality of the fit.
- Combinations of Wilson coefficients to which measurements are not sensitive manifest themselves as flat directions in the likelihood.
- These directions are identified using the Fisher information matrix of the original $H \to \gamma\gamma$ STXS likelihood (C^{-1}_{STXS}), parameterised in terms of the STXS parameters and obtained using the HESSE method within Minuit.

covariance matrix

Sensitivity Study

- Removing degenerate directions in the likelihood
- Keep only the sensitivity directions for final fits

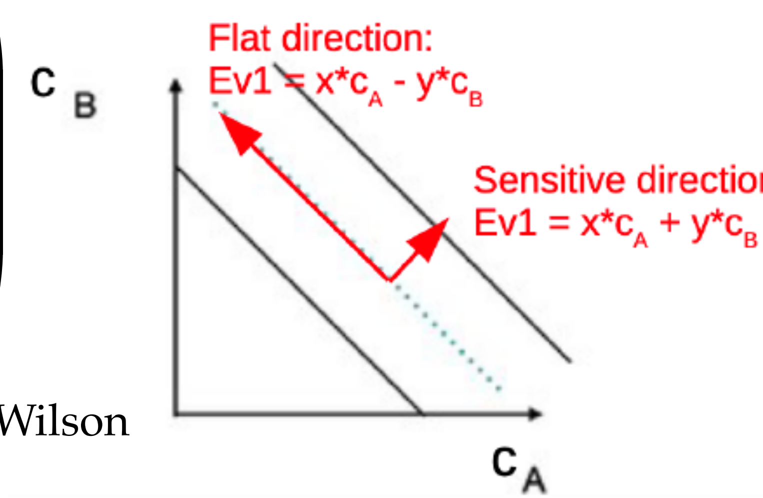
[Linear Algebra]

STXS X BR covariance matrix

SMEFTsim

SMEFT@NLO

$$C^{-1}_{\mathrm{EFT}} = P^T C^{-1}_{\mathrm{STXS}} P \quad \longrightarrow \quad P = \begin{pmatrix} A_0^{b_0} & A_1^{b_0} & A_2^{b_0} & \dots \\ A_0^{b_1} & A_1^{b_1} & A_2^{b_1} & \dots \\ A_0^{b_2} & A_1^{b_2} & A_2^{b_2} & \dots \\ \vdots & \vdots & \vdots & \end{pmatrix}$$



- C_{EFT}: covariance matrix of the Wilson coefficients;
- C_{STXS}: covariance matrix of the STXS cross sections;
- P: matrix that gives the parametrisation of the STXS bin cross sections as a function of the Wilson coefficients;
- $A_i^{b_j}$: factors obtained from the simulation.

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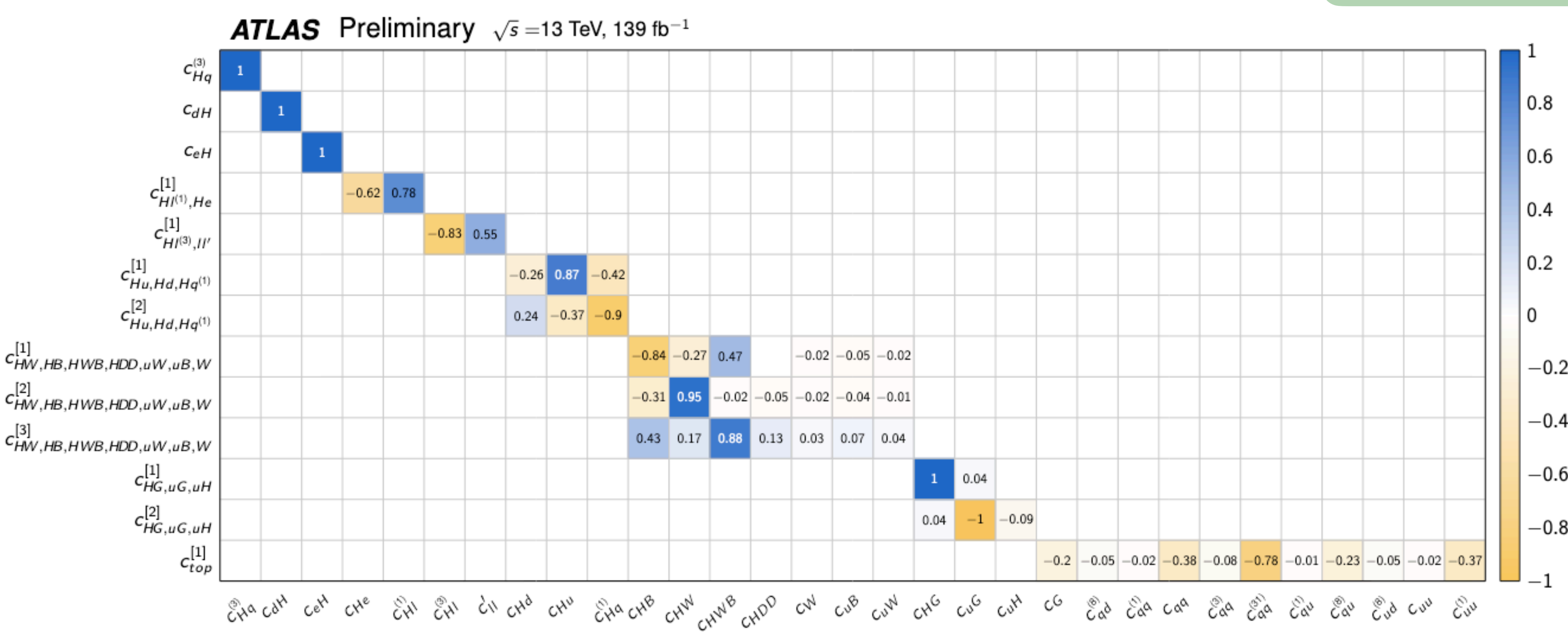
[Linear Algebra]



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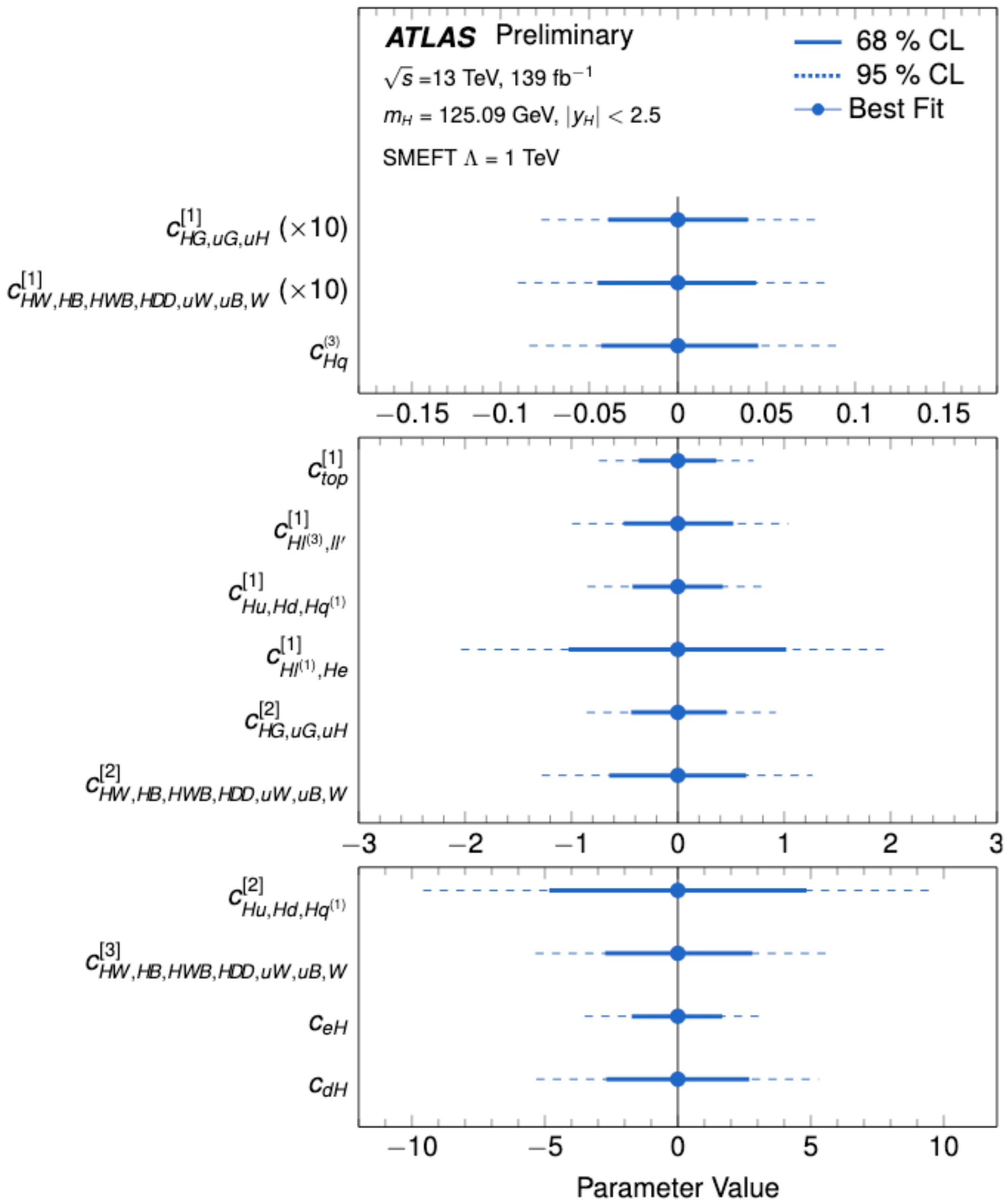
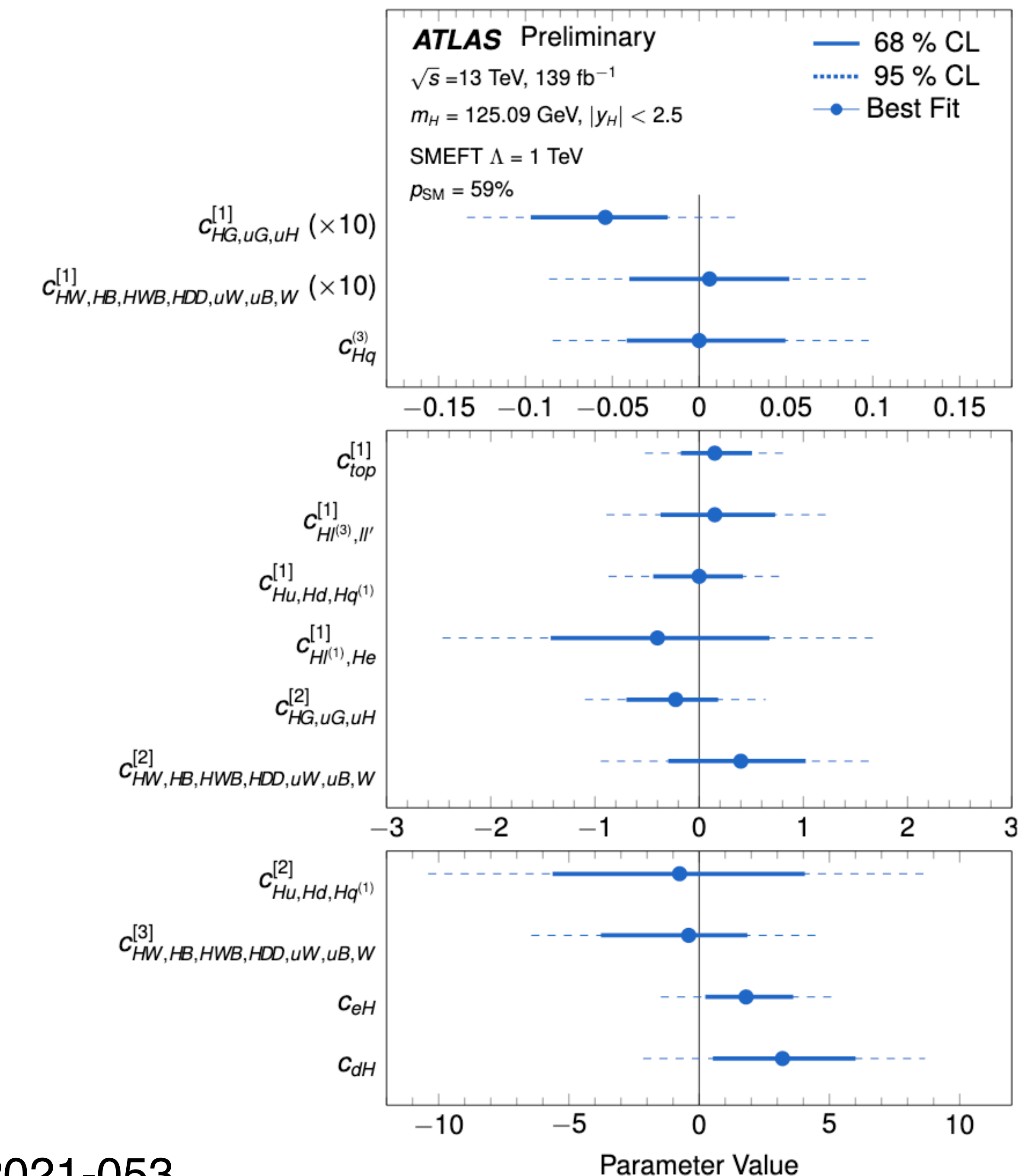
Summary of results (linear only)

Expected



Observed

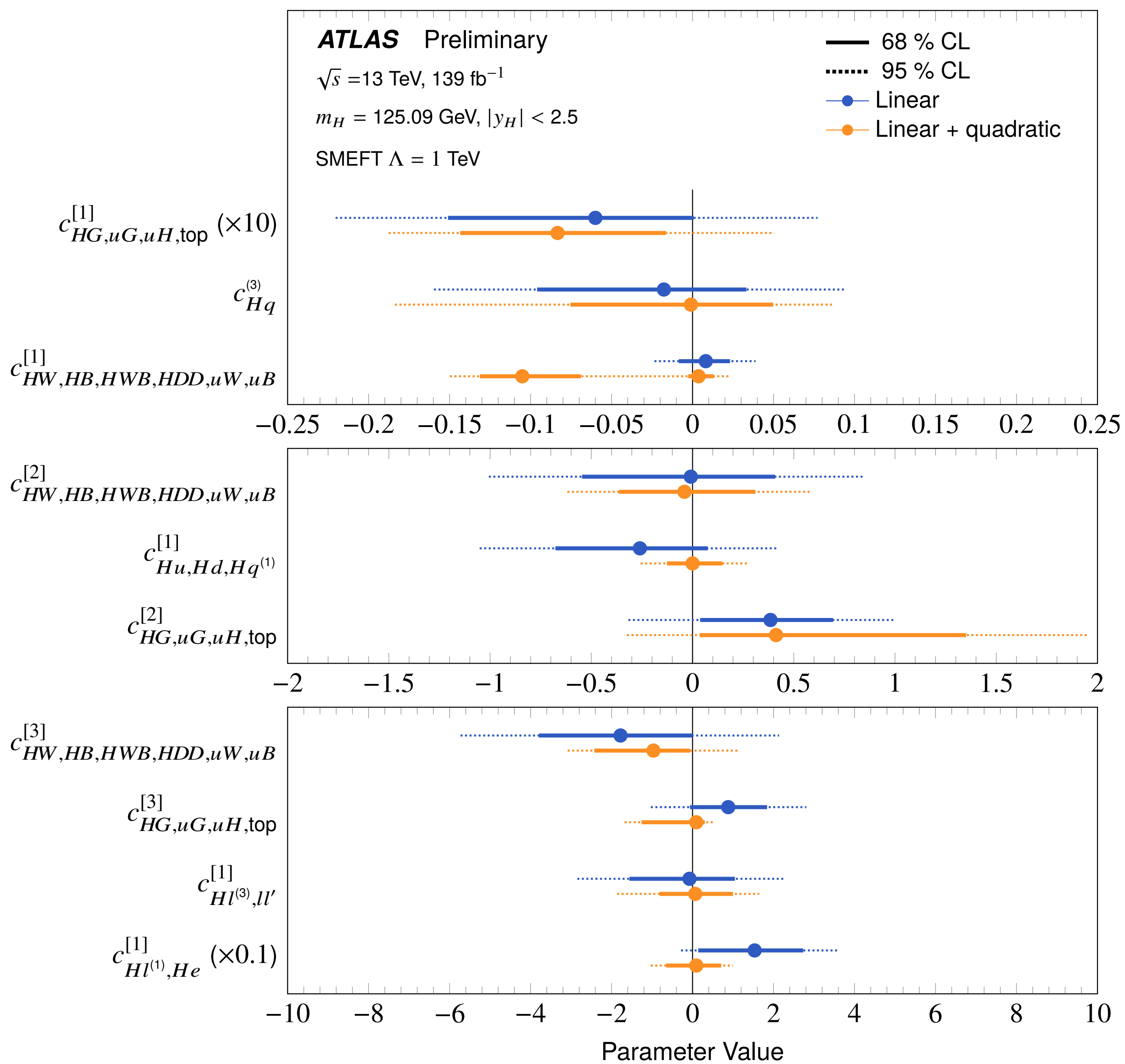


ATLAS-CONF-2021-053

- All measured parameters are consistent with the SM expectation within their uncertainty.
- Setting parameters to SM (zero) can be a strong model assumption-> in order to keep the generality of results, show that the impact on fitted directions is negligible within EFT validity range.

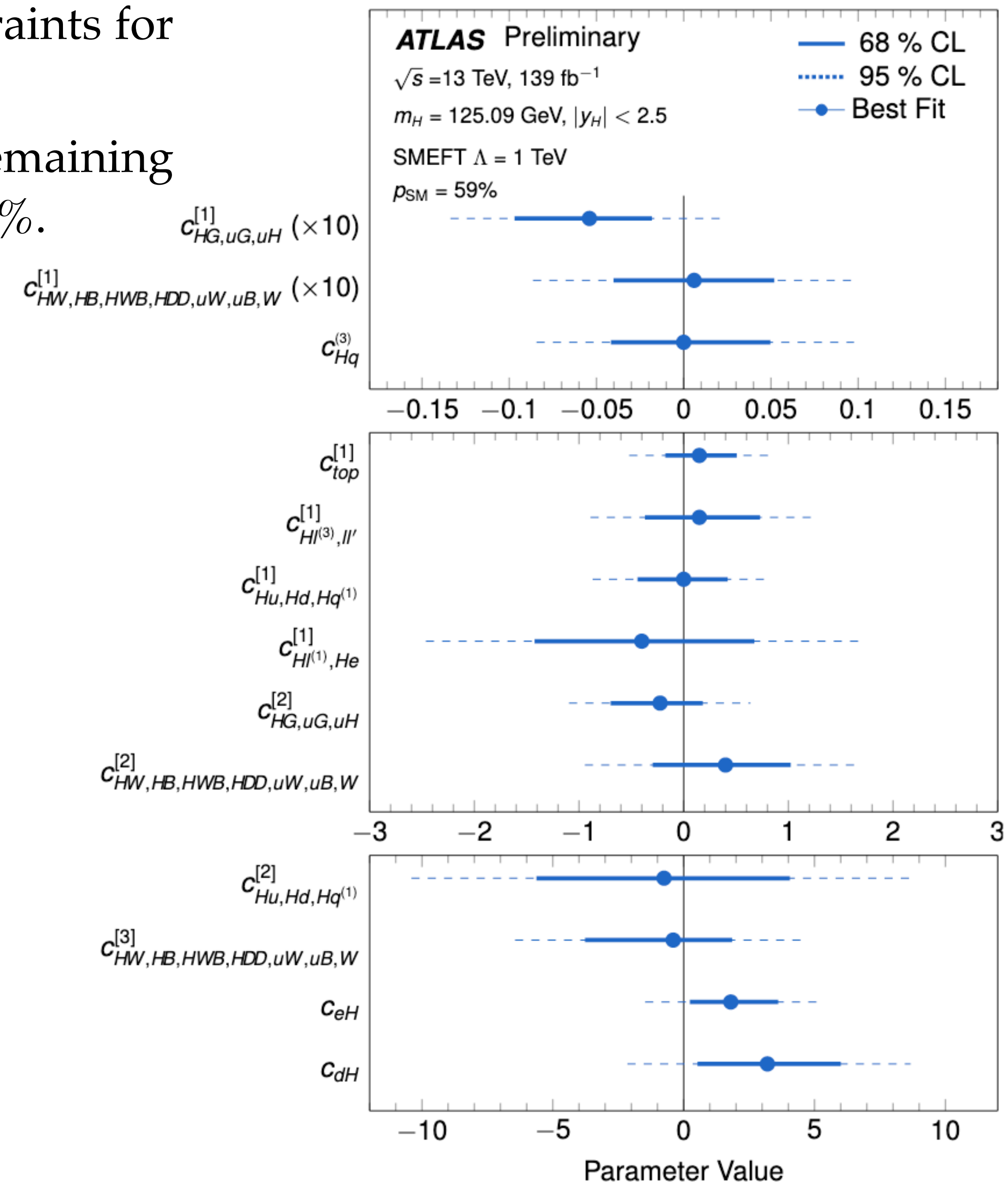
Summary of results (linear only)

- Additional sensitivity from the $H \to \tau\tau$, $VBF, H \to b\bar{b}$ and $t\bar{t}H, H \to b\bar{b}$ input channels-> c_{eH}, c_{dH} + independent constraints for $c_{top}^{[1]}$.
- Sensitivity to the most sensitive directions in each of the remaining groups of the parameters is in general improved by up to 70%.



ATLAS-CONF-2020-053 **ICHEP2020**

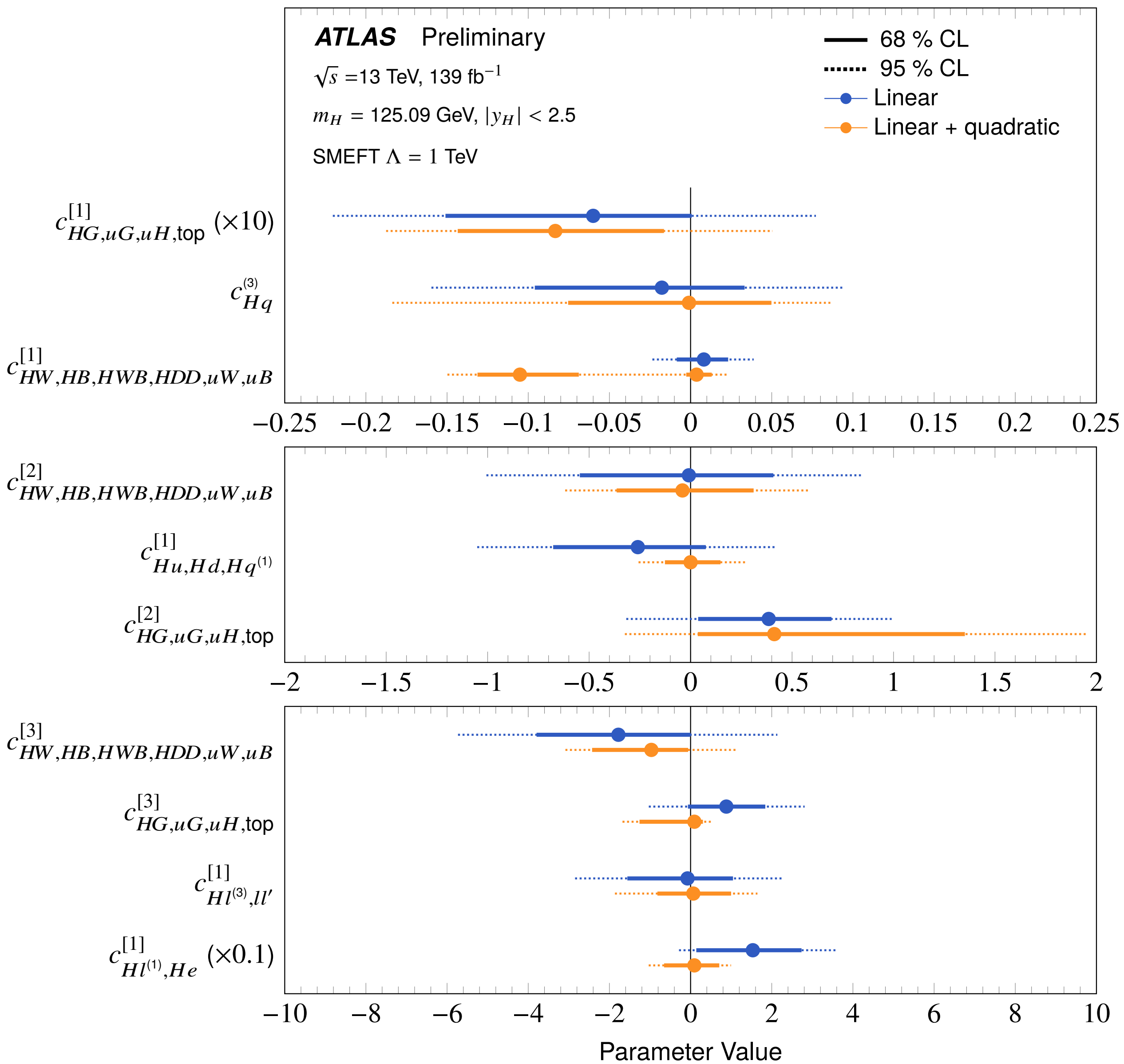
Observed

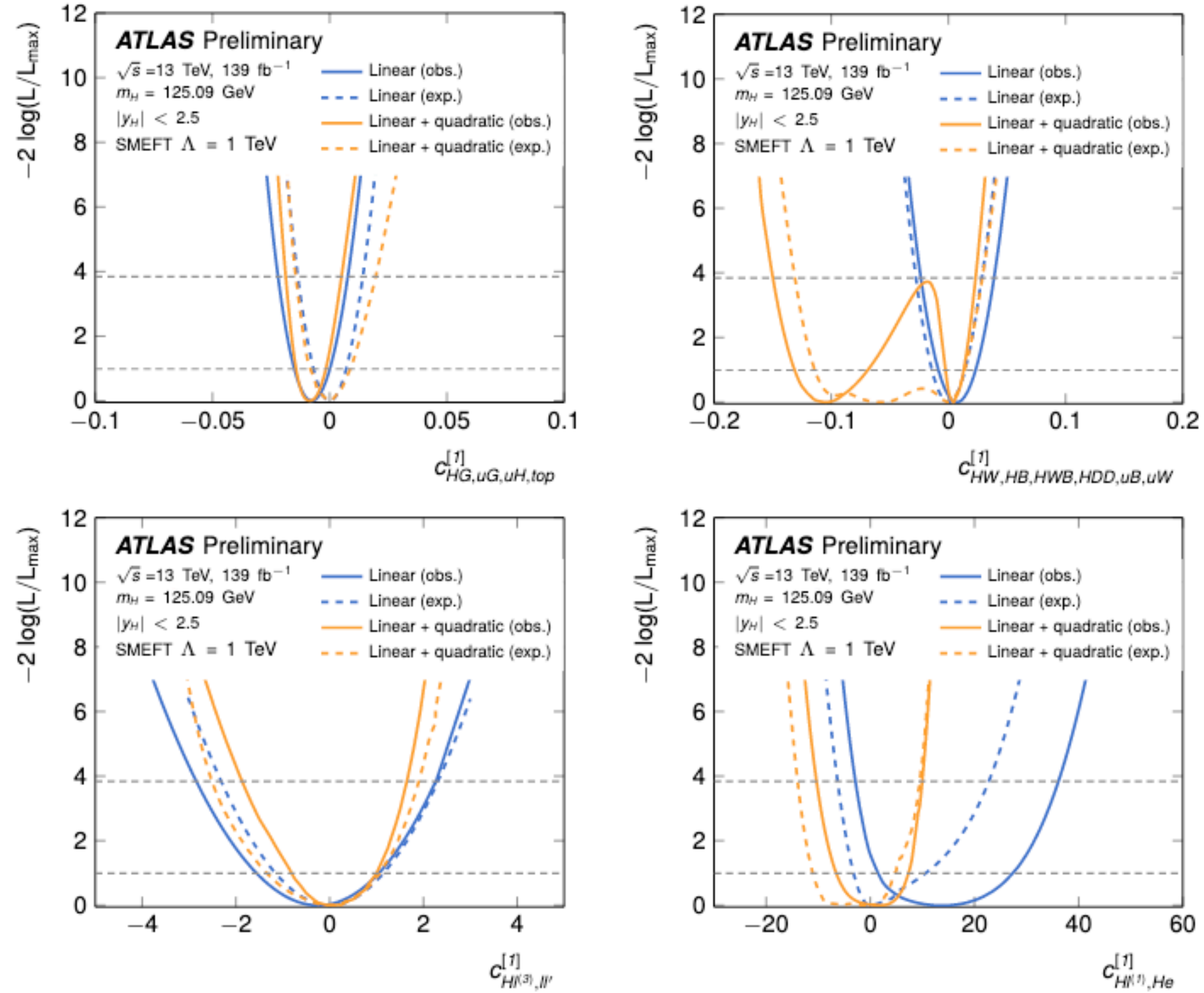


ATLAS-CONF-2021-053

Summary of results (linear+quadratic, ICHEP combination)

- Open point of the SMEFT interpretation, linear+quadratic theoretically robust? inclusion of quadratic terms: in some cases quadratic terms might drive the sensitivity -> study dim-8 terms since the Λ^4 term is not complete without these terms.





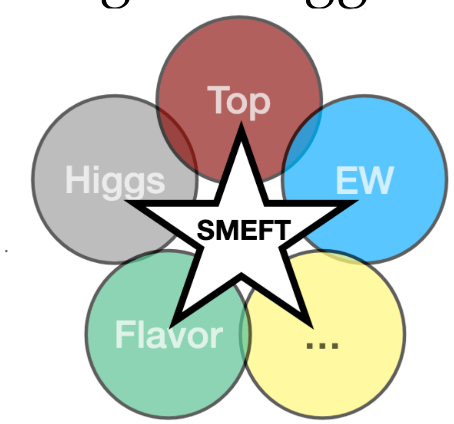
ICHEP2020 [ATLAS-CONF-2020-053]

Tyler Corbett, Adam Martin, and Michael Trott:
Consistent higher order $\sigma(gg \to H)$, $\Gamma(H \to gg)$ and $\Gamma(H \to \gamma\gamma)$ -> testing in $H \to \gamma\gamma$

Plans

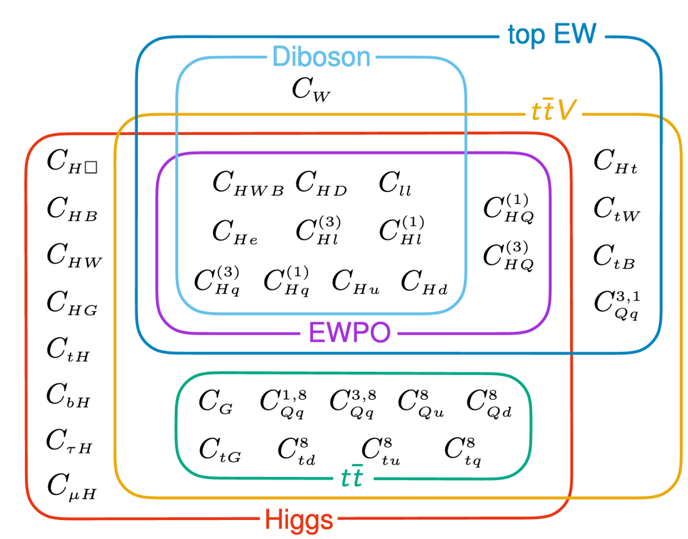
- Paper including EFT interpretations of $H \to \gamma\gamma$ channel.
- Paper including EFT interpretation of the Higgs combination-> more channels included, additional results provided for interpretations.

Higgs studies are just one input of global EFT analyses; furthermore, current Higgs measurements are not enough to disentangle all possible EFT interactions entering in Higgs physics-> avoid having to fix many coefficients to SM-> Combine analyses to get a more comprehensive picture!



- ATLAS Global EFT-> effort to combine Higgs, top, EW (+LEP constraints):
  - experience with interpretations in Higgs combination and H->WW+WW;
  - make use of the best knowledge of our measurement correlations.

- Likelihood-level EFT combination including EW, Higgs & top measurements from ATLAS & CMS (LHC EFT Twiki).
  - Exercise with CMS-> first combination using public results -> discussion ongoing to understand which analyses can be included for a first exercise (Twiki)



- Very active field both from experimental and theoretical point of view:
  - e.g. dim-8 contributions + theory uncertainties for EFT truncation + matching with UV models (From Models to SMEFT and Back)

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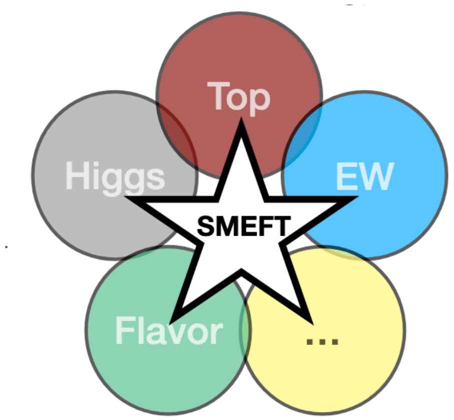
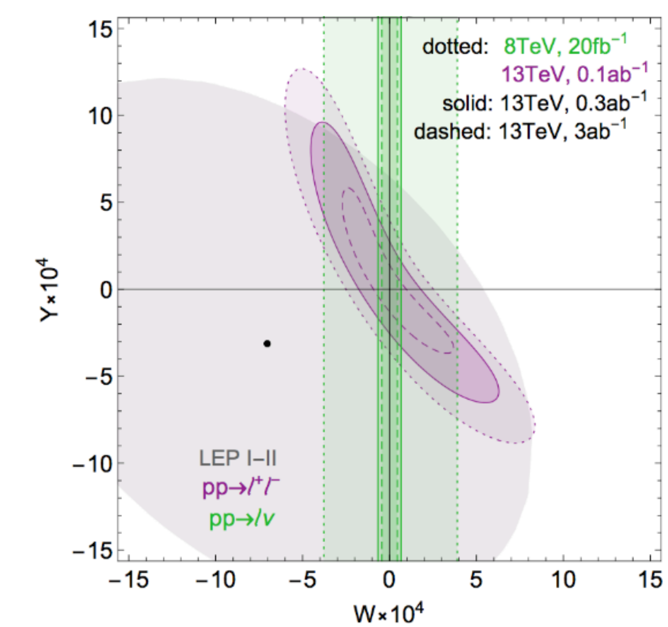


- The LAPP group is active also in **High Mass (mll>116 GeV) Drell Yan studies**.
- Measurements of beauty hadron decays from **LHCb** display a seemingly coherent pattern of deviations with respect to the SM predictions, which suggest that new physics couples differently to three generations of matter.
- quark-level processes responsible for these so-called 'B anomalies' could be connected to $b\bar{s} \to ll$ and $b\bar{c} \to l\nu \to ll$ and $b\bar{c} \to l\nu$ and $b\bar{c} \to l\nu \to l\nu$ scattering processes by crossing symmetry.
- Search for deviation from the SM prediction in the cross sections of the Drell -Yan process, for all three lepton families consistently, studying single/ double differential DY cross section, trying to optimise the sensitivity of the analysis to new phenomena throughout EFT effects (L3 - M2 students have worked /will work on this!!).

arXiv: 1609.08157 (HL-LHC)



Thanks for your attention!

New SMEFTsim v3.0

	general		U35		MFV		top		topU3l	
	all	$\cancel{CP}$	all	$\cancel{CP}$	all	$\cancel{CP}$	all	$\cancel{CP}$	all	$\cancel{CP}$
$\mathcal{L}_6^{(1)}$	4	2	4	2	2	-	4	2	4	2
$\mathcal{L}_6^{(2,3)}$	3	-	3	-	3	-	3	-	3	-
$\mathcal{L}_6^{(4)}$	8	4	8	4	4	-	8	4	8	4
$\mathcal{L}_6^{(5)}$	54	27	6	3	7	-	14	7	10	5
$\mathcal{L}_6^{(6)}$	144	72	16	8	20	-	36	18	28	14
$\mathcal{L}_6^{(7)}$	81	30	9	1	14	-	21	2	15	2
$\mathcal{L}_6^{(8a)}$	297	126	8	-	10	-	31	-	16	-
$\mathcal{L}_6^{(8b)}$	450	195	9	-	19	-	40	2	27	2
$\mathcal{L}_6^{(8c)}$	648	288	8	-	28	-	54	4	31	4
$\mathcal{L}_6^{(8d)}$	810	405	14	7	13	-	64	32	40	20
tot	2499	1149	85	25	120	-	275	71	182	53

From Ilaria's talk

New SMEFTsim v3.0

SMEFTsim ★ v3.0 ★

SMEFTsim package:

- LO tool with effective vertices for ggH, $H \to \gamma\gamma$ and $H \to Z\gamma$ ($H \to gg$).
- Different flavour assumptions included ($(U(3))^5$ flavour symmetry);
- Two input parameter schemes (M_W-scheme).
- Truncation of the Lagrangian at $1/\Lambda^2$.

Follow standards for **top quark physics** proposed in Aguilar-Saavedra et al 1802.07237

Based on $U(2)$ symmetry in quark sector — Barbieri et al. 1105.2296,1203.4218

→ 1st, 2nd gen.	(q_L, u_R, d_R)	$U(2)_q \times U(2)_u \times U(2)_d$
→ 3rd gen.	(Q_L, t_R, b_R)	no sym

$V_{CKM} \equiv \mathbb{1}$

- quarks of the first two generations and quarks of the 3rd are described by independent fields.

Two alternative options for lepton sector

`top`	$[U(1)_{l+e}]^3$	• corresponds to simple flavor-diagonality → only diagonal entries. allows $e \neq \mu \neq \tau$
`topU3l`	$U(3)_l \times U(3)_e$	→ same as $U(3)^5$ model. diagonal + $e = \mu = \tau$ imposed

In the lepton sector, this setup matches exactly the structure of the U35 and MFV models. More restrictive w.r.t top scheme

SMEFTsim 3.0, I.Brivio

- Linear propagator corrections added to the package: mass terms and decay widths of the SM particles generally receive corrections from dim-6 operators-> include them in order to compute amplitudes consistently at $O(\Lambda^{-2})$.

$qq \to Hqq$ production: negligible effect in VBF bins, significant in VH ones

$$\frac{\sigma_{SMEFT}}{\sigma_{SM}} = 1 - 0.29\,\frac{\delta\Gamma_Z}{\Gamma_Z^{SM}} - 0.65\,\frac{\delta\Gamma_W}{\Gamma_W^{SM}} + \text{direct}$$

Example of correction for VH

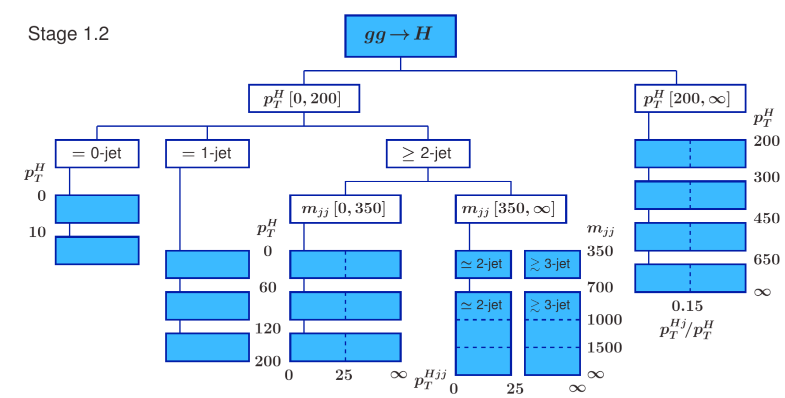
Higgs-boson properties: precision measurements

Two complementary measurements used to explore the properties of the Higgs boson:

Fiducial cross sections:

- largely model-independent measurements.
- Include information on the decay.
- Different distributions can be measured.
- Fiducial selection matches experimental selection (reduce full phase space extrapolation).

LHCHWGFiducialAndSTXS



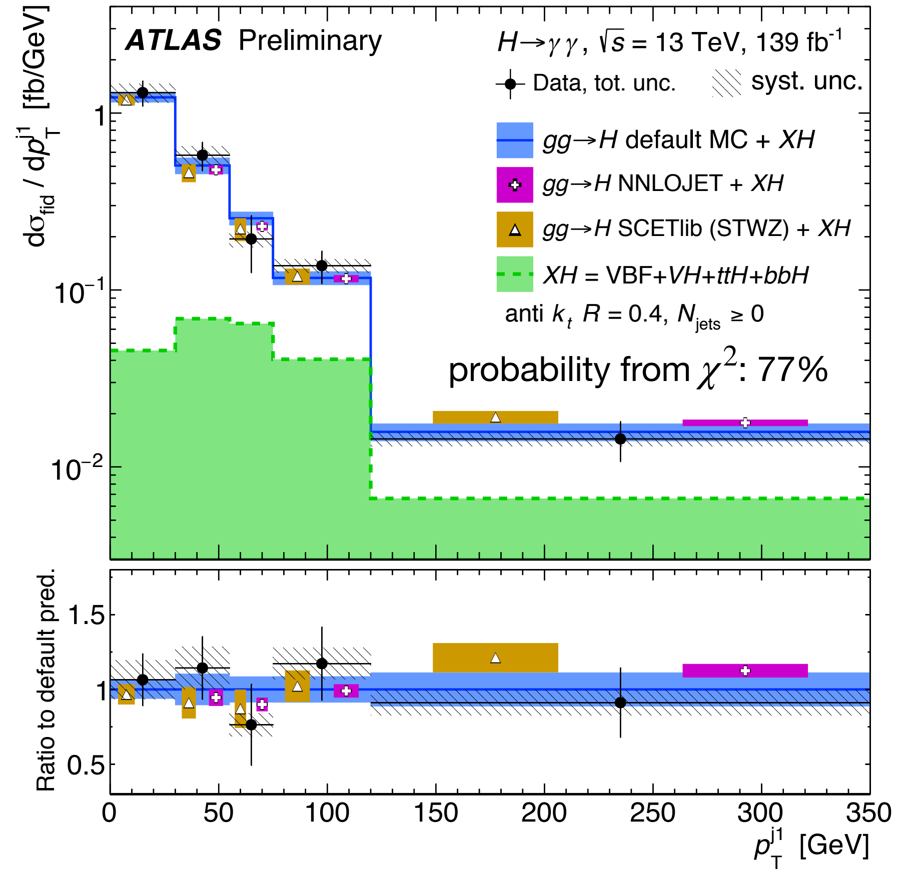
Simplified template cross section (STXS):

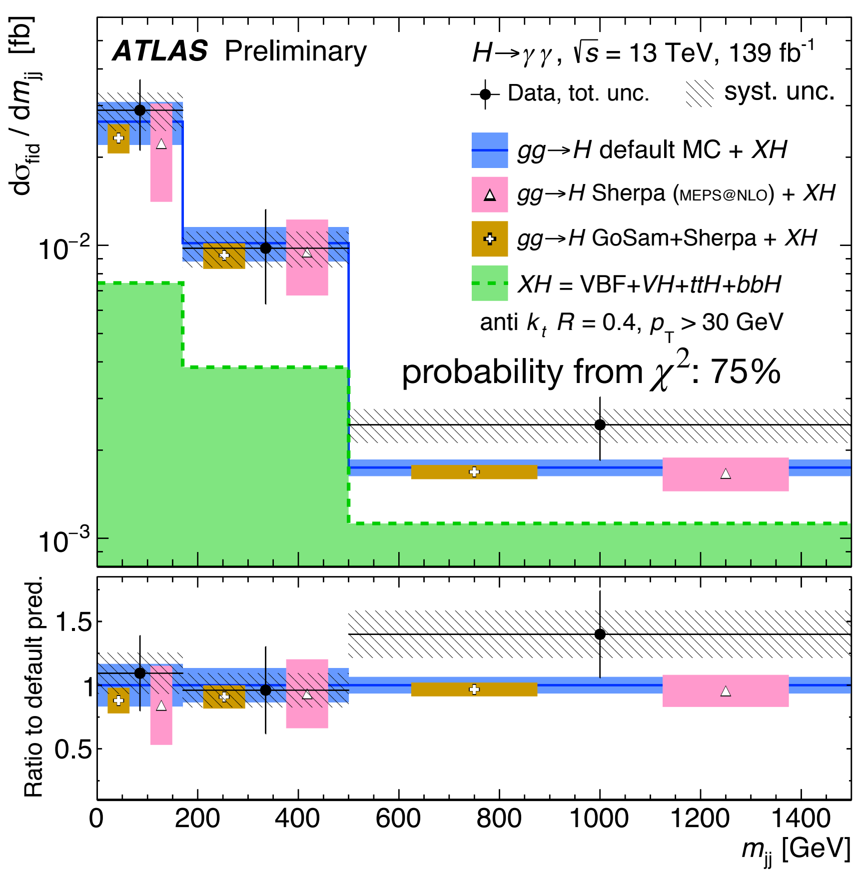
- STXS targets phase space regions within production modes, using Standard Model kinematics as a template.
- Categorise each production mode in bins of key (truth) quantities (p_T^H, N_{jets}, m_{jj}, …).
- Reduce theory systematics, but more model-dependent.
- No decay information available in STXS (for the moment).

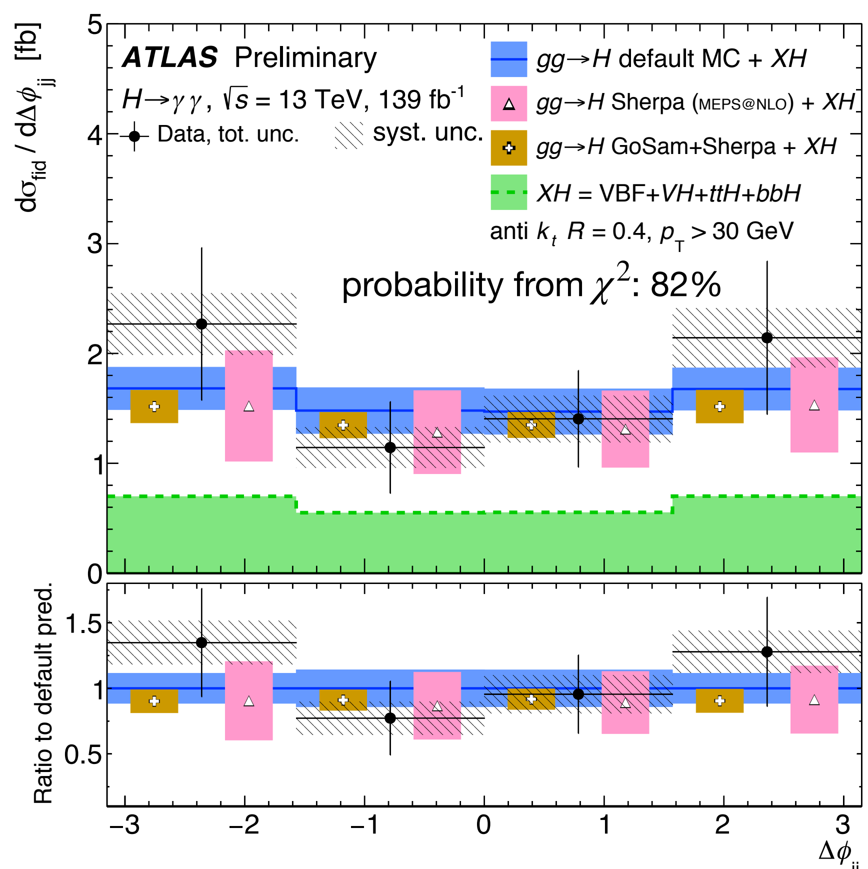
$H \rightarrow \gamma\gamma$: differential and fiducial cross sections

- The distributions are compared to the state-of-the art theory predictions and used for the interpretations.

- Kinematics observables with sensitivity to new physics.
- $\Delta\phi_{jj}$: sensitive to CP properties of the Higgs boson.
- Good agreement observed w.r.t. SM predictions.







ATLAS-CONF-2019-029

Anomalous Higgs-boson interactions through EFT

An effective field theory (EFT) approach can be used to interpret Higgs-boson interactions:

- additional CP-even and CP-odd interactions can change the event rates, the kinematic properties of the Higgs boson, etc.., from those predicted by the SM.

$$\mathscr{L}_{EFT} = \mathscr{L}_{SM} + \sum_{i,D} \frac{c_i^{(D)}}{\Lambda^{D-4}} \mathcal{O}_i^{(D)}$$

Wilson coefficients

- The differential $H \to \gamma\gamma$ cross sections are sensitive to operators that affect the Higgs-boson interactions with gauge bosons (5 differential distributions).

$$d(\sigma \times BR)/dx,\ x = p_T^{\gamma\gamma}, N_{jets}, p_T^{j1}, m_{jj}, \Delta\varphi_{jj}$$

- Two different EFT basis have been used:
  - ✦ the SILH basis of the Higgs Effective Lagrangian
  - ✦ the Warsaw basis of the SMEFT Lagrangian.

$$\mathcal{L}_{\rm eff}^{\rm SILH} \supset \bar{c}_g O_g + \bar{c}_\gamma O_\gamma + \bar{c}_{HW} O_{HW} + \bar{c}_{HB} O_{HB} + \tilde{c}_g \tilde{O}_g + \tilde{c}_\gamma \tilde{O}_\gamma + \tilde{c}_{HW} \tilde{O}_{HW} + \tilde{c}_{HB} \tilde{O}_{HB}$$

$$\mathcal{L}_{\rm eff}^{\rm SMEFT} \supset \bar{C}_{HG} O'_g + \bar{C}_{HW} O'_{HW} + \bar{C}_{HB} O'_{HB} + \bar{C}_{HWB} O'_{HWB} + \tilde{C}_{HG} \tilde{O}'_g + \tilde{C}_{HW} \tilde{O}'_{HW} + \tilde{C}_{HB} \tilde{O}'_{HB} + \tilde{C}_{HWB} \tilde{O}'_{HWB}$$

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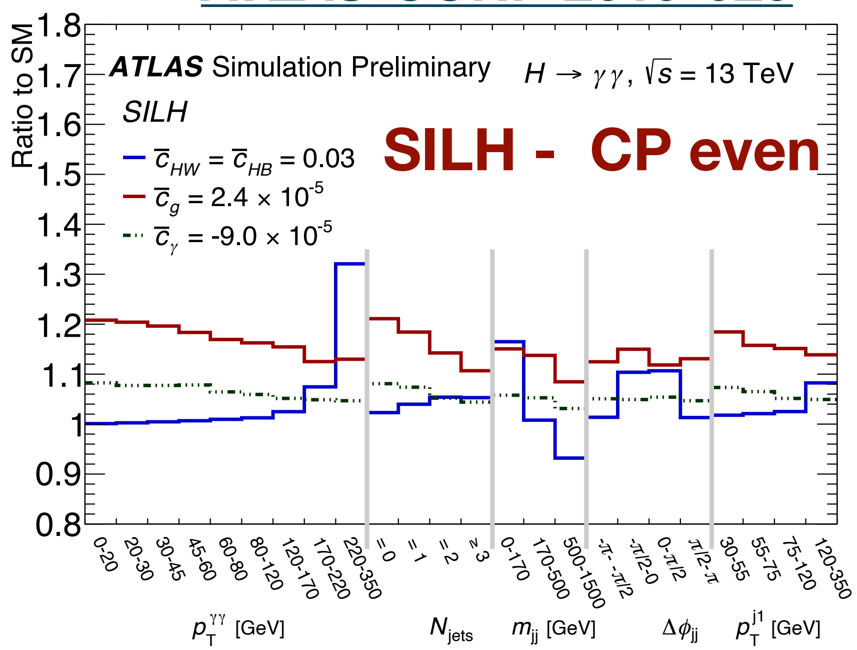

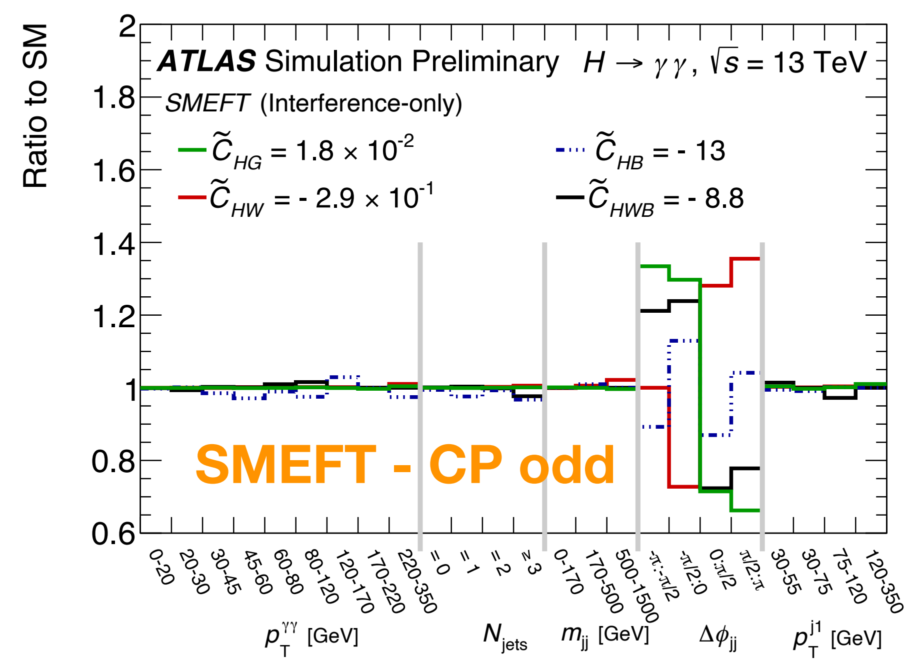

Plots including CP-odd (SILH) and CP-even (SMEFT) are in backup

Anomalous Higgs-boson interactions through EFT

- 1D and 2D limits obtained fitting one or two WC at the time (and fixing the others to 0 -> SM).

$$\mathcal{L}_{\mathrm{eff}}^{\mathrm{SILH}} \supset \quad \bar{c}_g O_g + \bar{c}_\gamma O_\gamma + \bar{c}_{HW} O_{HW} + \bar{c}_{HB} O_{HB} + \tilde{c}_g \widetilde{O}_g + \tilde{c}_\gamma \widetilde{O}_\gamma + \tilde{c}_{HW} \widetilde{O}_{HW} + \tilde{c}_{HB} \widetilde{O}_{HB}$$

- Destructive interference causes the ggF production cross section=0 around $\bar{c}_g \sim -2.2 \cdot 10^{-4}$ for $\tilde{c}_g \sim 0$-> structure seen in the observed limits in the two-dimensional parameter plane.

$$\mathcal{L}_{\mathrm{eff}}^{\mathrm{SMEFT}} \supset \quad \overline{C}_{HG} O'_g + \overline{C}_{HW} O'_{HW} + \overline{C}_{HB} O'_{HB} + \overline{C}_{HWB} O'_{HWB} + \widetilde{C}_{HG} \widetilde{O}'_g + \widetilde{C}_{HW} \widetilde{O}'_{HW} + \widetilde{C}_{HB} \widetilde{O}'_{HB} + \widetilde{C}_{HWB} \widetilde{O}'_{HWB}$$

- The limits in the interference and interference + pure BSM cases are very similar for coefficients of CP-even operators (interference terms dominate).
- Significant differences emerge for the CP-odd ones for which the interference term is vanishing (for inclusive observables).

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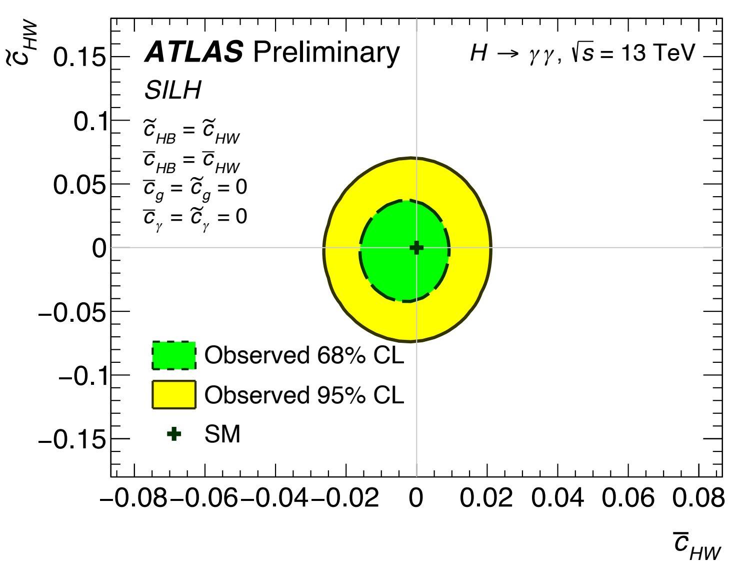
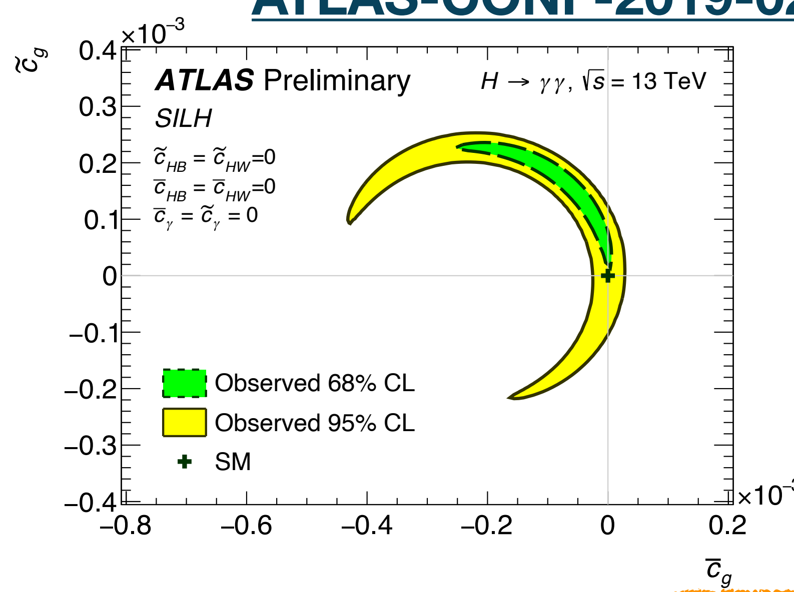
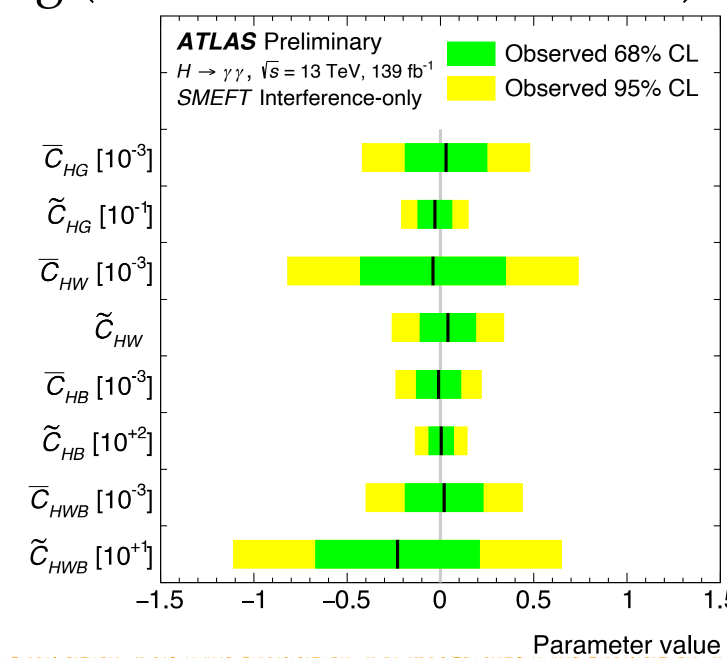


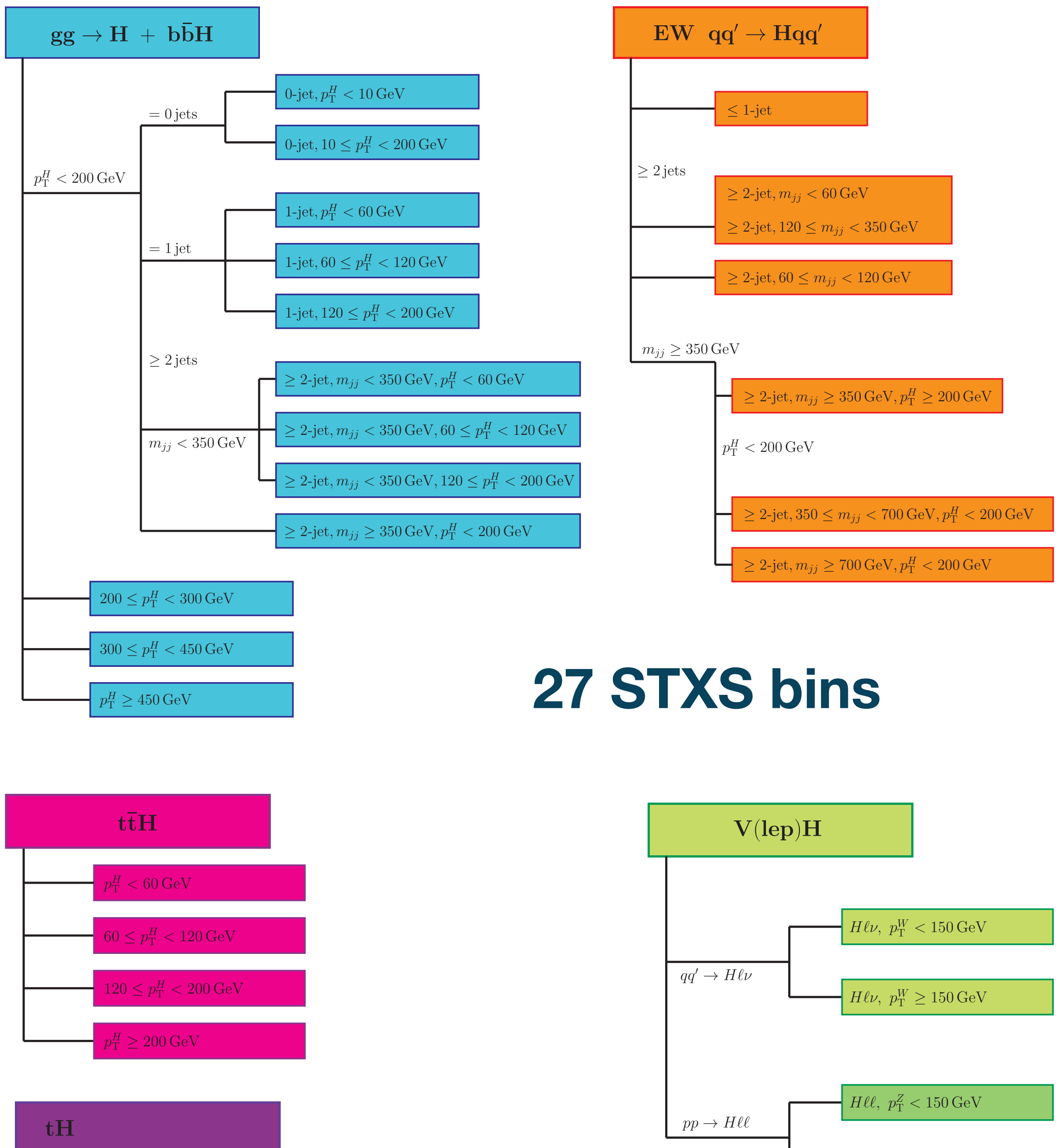




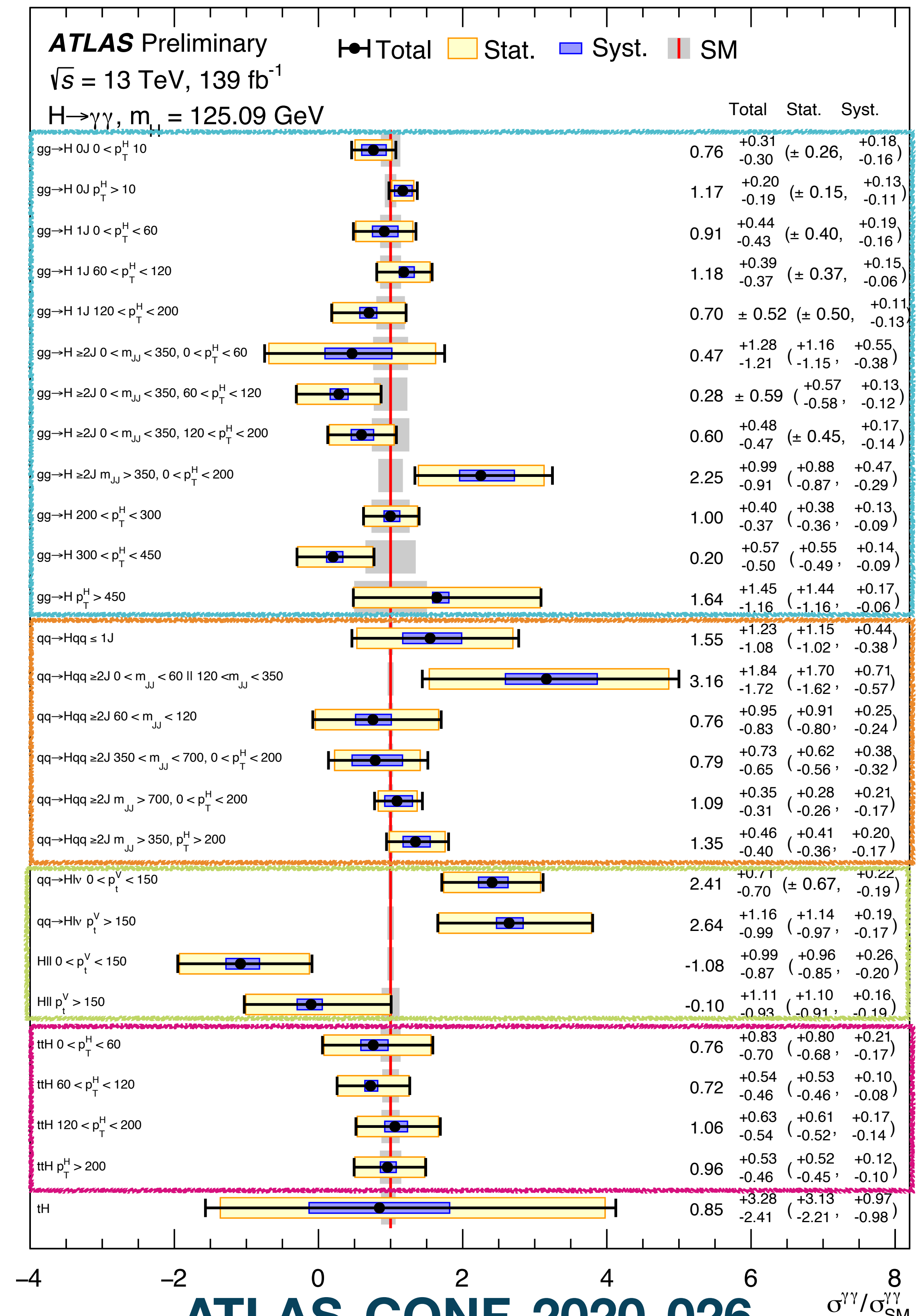
Coefficient	Observed 95% CL limit	Expected 95% CL limit
$\bar{c}_g$	$[-0.26, 0.26] \times 10^{-4}$	$[-0.25, 0.25] \cup [-4.7, -4.3] \times 10^{-4}$
$\tilde{c}_g$	$[-1.3, 1.1] \times 10^{-4}$	$[-1.1, 1.1] \times 10^{-4}$
$\bar{c}_{HW}$	$[-2.5, 2.2] \times 10^{-2}$	$[-3.0, 3.0] \times 10^{-2}$
$\tilde{c}_{HW}$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

Coefficient	95% CL, interference-only terms	95% CL, interference and quadratic terms
$\overline{C}_{HG}$	$[-4.2, 4.8] \times 10^{-4}$	$[-6.1, 4.7] \times 10^{-4}$
$\widetilde{C}_{HG}$	$[-2.1, 1.6] \times 10^{-2}$	$[-1.5, 1.4] \times 10^{-3}$
$\overline{C}_{HW}$	$[-8, 2, 7.4] \times 10^{-4}$	$[-8.3, 8.3] \times 10^{-4}$
$\widetilde{C}_{HW}$	$[-0.26, 0.33]$	$[-3.7, 3.7] \times 10^{-3}$
$\overline{C}_{HB}$	$[-2.4, 2.3] \times 10^{-4}$	$[-2.4, 2.4] \times 10^{-4}$
$\widetilde{C}_{HB}$	$[-13.0, 14.0]$	$[-1.2, 1.1] \times 10^{-3}$
$\overline{C}_{HWB}$	$[-4.0, 4.4] \times 10^{-4}$	$[-4.2, 4.2] \times 10^{-4}$
$\widetilde{C}_{HWB}$	$[-11.1, 6.5]$	$[-2.0, 2.0] \times 10^{-3}$

$H \to \gamma\gamma$: STXS cross sections



27 STXS bins

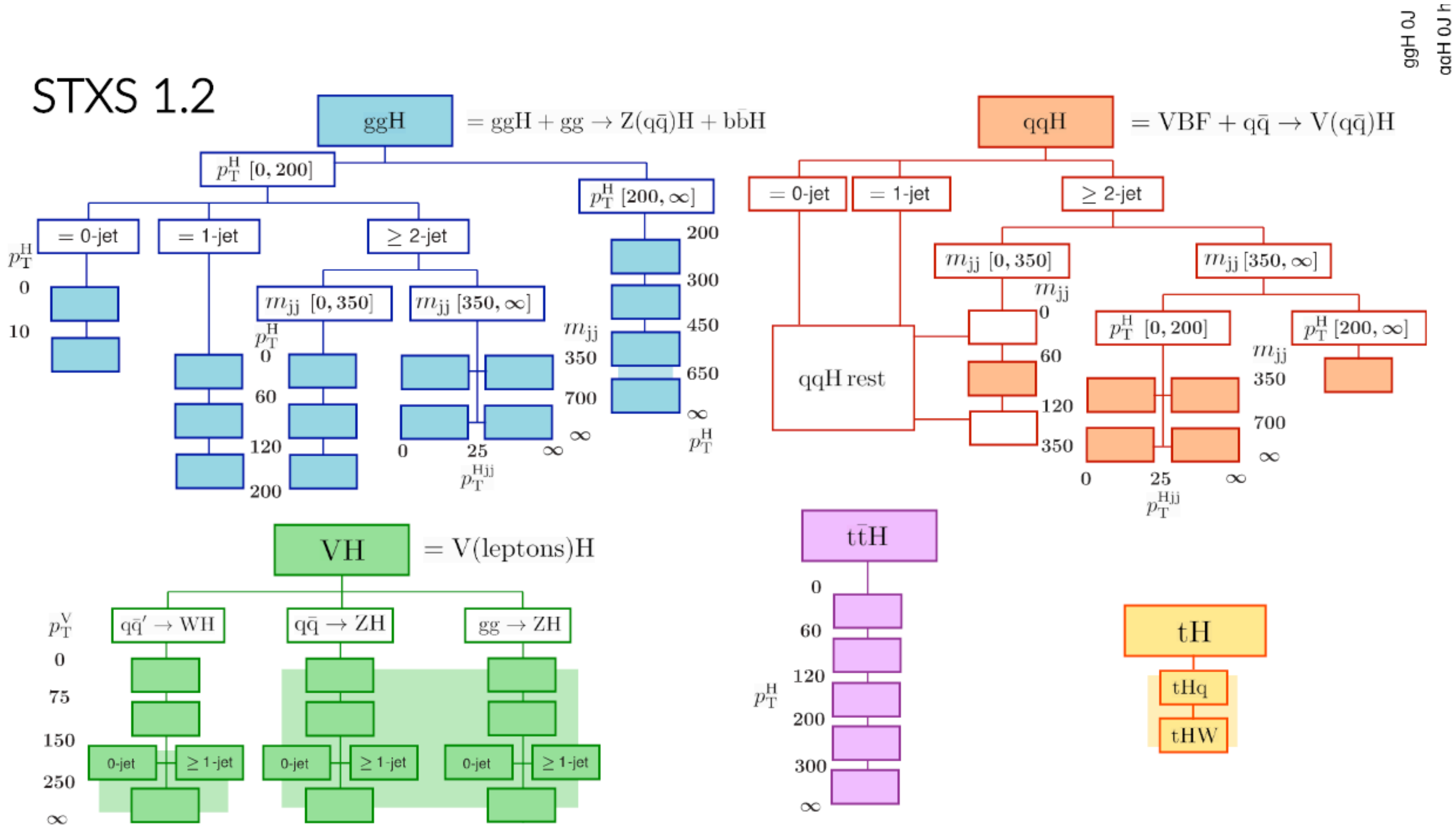


ATLAS-CONF-2020-026

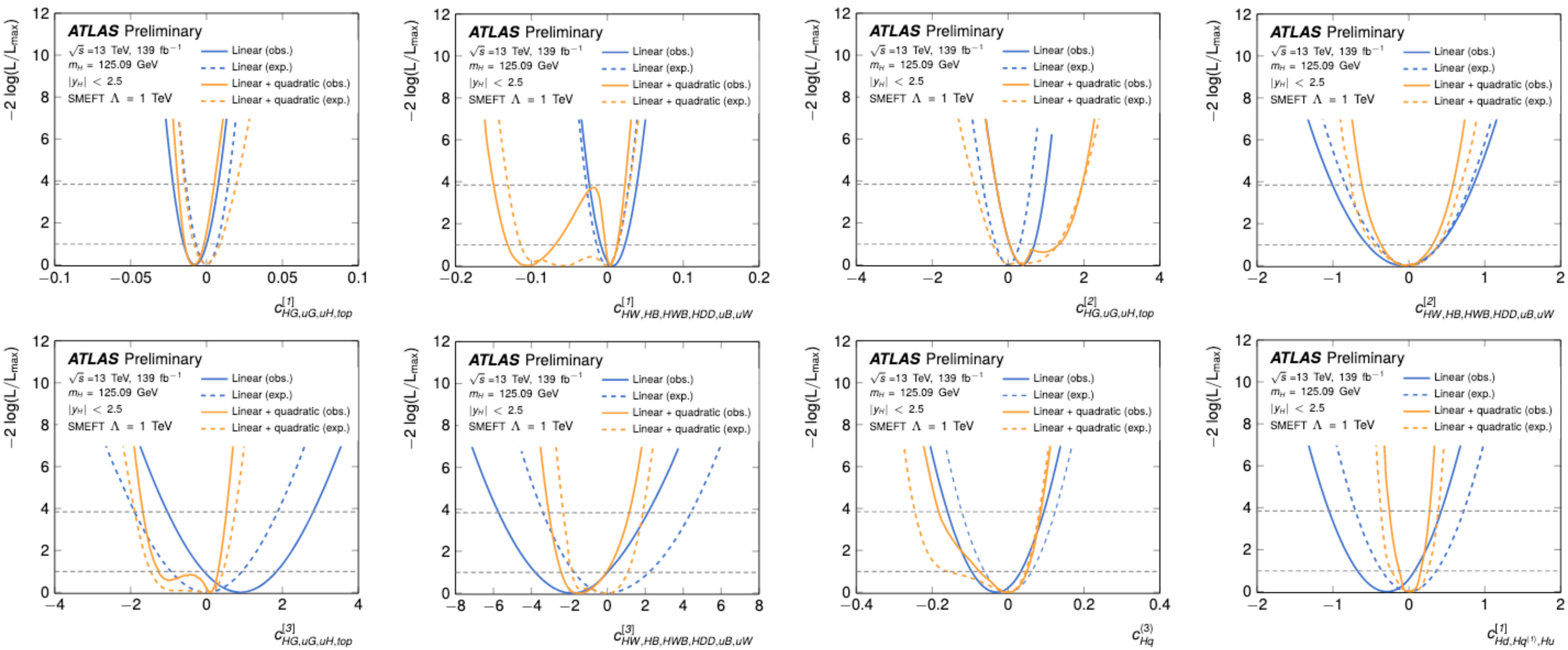
- The relative uncertainties on the measurements range from 20% to more than 100%.

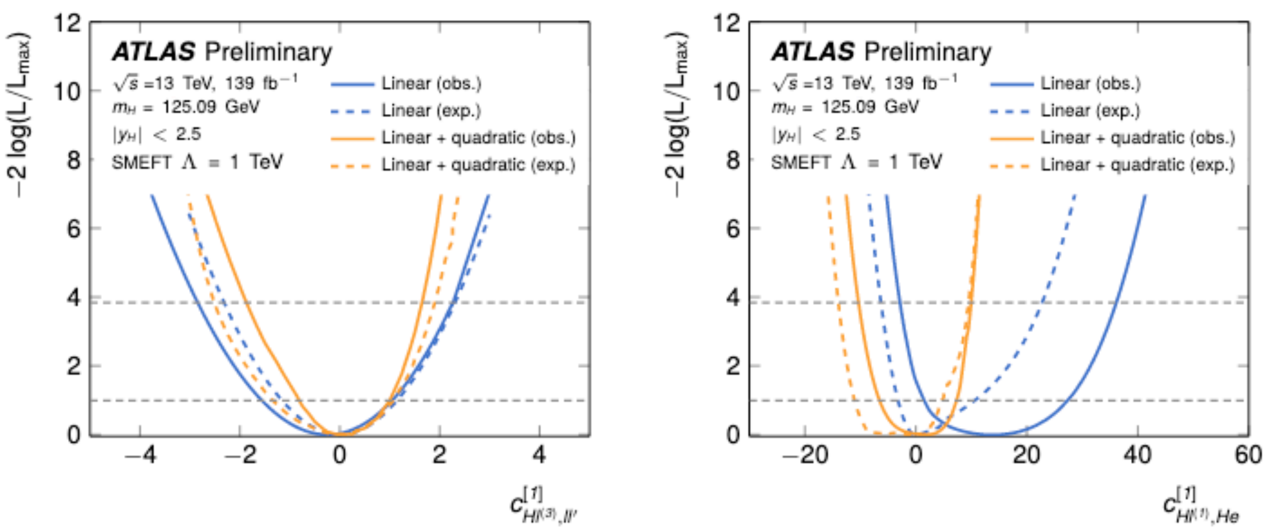
STXS Stage 1.2

- Physical cross sections defined in mutually exclusive regions of phase space (bins).
- Simplified kinematic cuts: measurements unfolded to STXS bins → facilitate ATLAS and CMS combination
- Cuts defined for specific production modes, with the SM serving as kinematic template.
- Minimise dependence on theory uncertainty folded into the measurements.
- Maximise experimental sensitivity.
- Isolate possible BSM effects.
- Limit number of bins to match the experimental sensitivity ⇒ this number evolves as data increases.



Impact of quadratic terms





ATLAS-CONF-2020-053 **ICHEP2020**

Non-negligible impact from quadratic terms-> study dim-8 terms

EFT parameterisation

- Analyses primarily measure cross-sections (or signal strengths) with likelihood fit

$$L(\boldsymbol{\mu}, \boldsymbol{\theta}) = \prod_i^{\text{bins}} P\left(n_i^{\text{obs}} \mid \mu_i n_i^{\text{sig}}(\boldsymbol{\theta}) + n_i^{\text{bkg}}(\boldsymbol{\theta})\right) \cdot \prod_j^{\text{nuis}} G(\theta_j)$$

- For direct interpretations, we should replace the number of signal events:

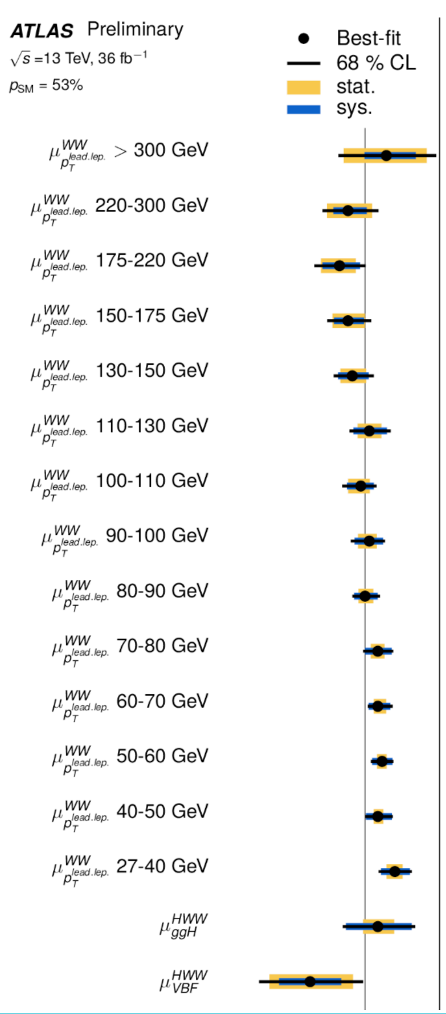
$$n^{\text{sig}}(\boldsymbol{c}) \cdot \mathcal{L}^{-1} = \sigma_{\text{SM}} + \overbrace{\sum_j \frac{c_j}{\Lambda^2} \int \left|\mathcal{M}_{\text{SM}}^{d-1} \mathcal{O}_j^{(6)}\right| d\Omega}^{\text{“linear”}} + \overbrace{\sum_{jk} \frac{c_j c_k}{\Lambda^4} \int \left|\mathcal{M}_{\text{SM}}^{d-2} \mathcal{O}_j^{(6)} \mathcal{O}_k^{(6)}\right| d\Omega}^{\text{“quadratic”}} + \ldots$$

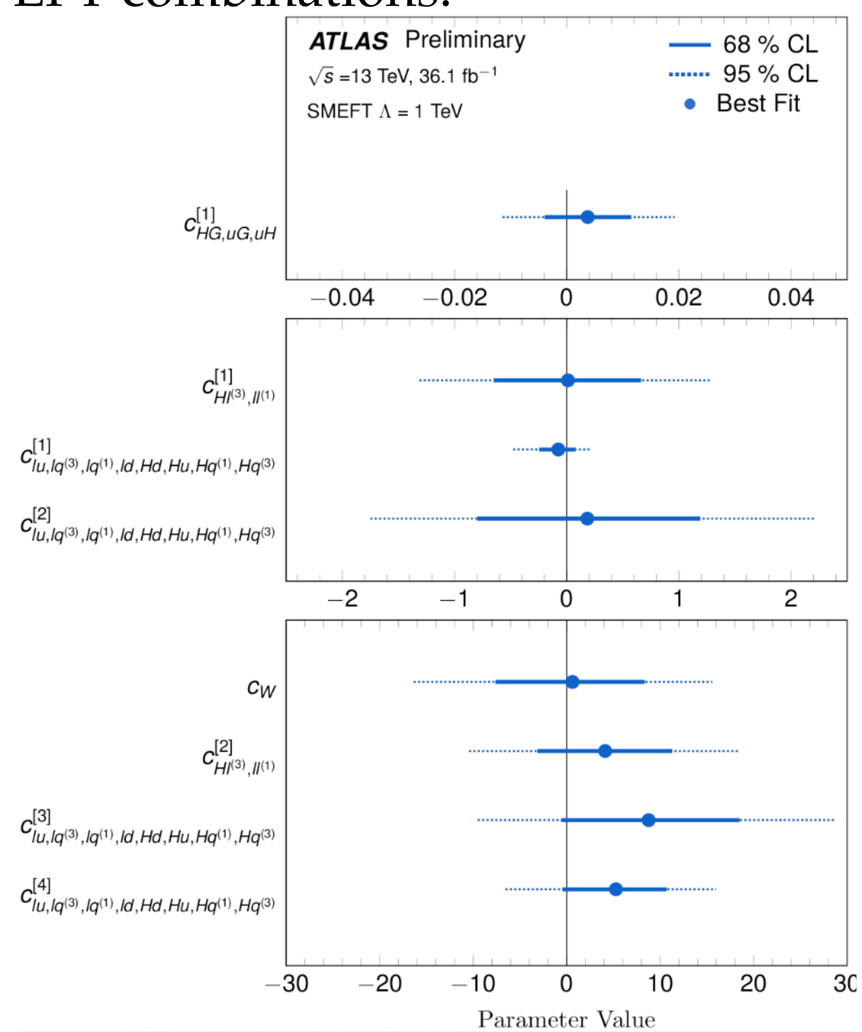
- For indirect interpretations (like differential measurements), perform the same procedure on the cross-sections in the rewritten likelihood based on published, unfolded result with data bin correlation matrix C:

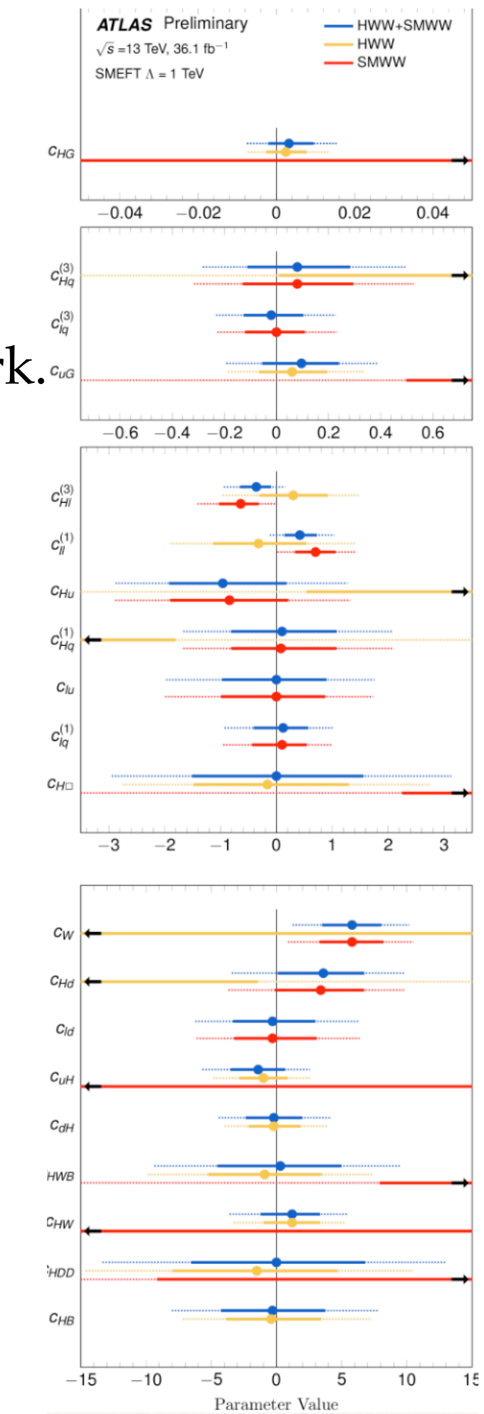
$$L(\boldsymbol{\Delta\sigma}) = \frac{1}{\sqrt{(2\pi)^{n_{\text{bins}}} \det C}} \exp\left(-\frac{1}{2} \boldsymbol{\Delta\sigma}^T C^{-1} \boldsymbol{\Delta\sigma}\right) \qquad \text{with } \Delta\sigma = \sigma^{\text{obs}} - \sigma^{\text{sig}}$$

HWW+ WW combination

- Combine unfolded WW distribution (14 bins - indirect interpretation, Gaussan likelihood) and H(WW*) ggF + H(WW*) VBF signal strength modifiers in likelihood (direct interpretation μggF/μVBF);
  - ★ correlated treatment of systematics;
  - ★ simultaneous fit of 8 coefficients;
  - ★ rotation to sensitive basis.
- Orthogonal SRs, but WW CR in H (WW∗) overlaps with SM WW signal.
  - ★ replace WW CR with SM WW measurement, correlate as appropriate.
- Constrain 22 Wilson coeffs. of bosonic and two-fermion operators in SMEFT framework.
- Stepping stone towards more global EFT combinations.







ATL-PHYS-PUB-2021-010

Clipping

Clipping approach

- Use the EFT prediction only up to a clipping energy $\sqrt{s} = E_{clip}$ and set any contribution from this theory to 0 beyond this energy
- The clipping is done at parton level
- The SM predictions as well as the data remain untouched
- Derive limits for various E_{clip}
- Considering to use: Last data point can be use as reference point to start clipping scan

JManjarres-LHCEFT

HM DY talk

High energy probes of EW sector

- High mass Drell-Yan measurements can indirectly probe heavy new physics
- Modification of the SM in self energies of vector bosons
  - Focus on oblique corrections: S, T, W, and Y
- W and Y modify the propagators off the pole
- W and Y modify the cross section by a factor that grows with energy as q^2/mV (can be generated by dim-6 EFT operators)
  - Is the energy enhancement at hadron colliders sufficient to beat the precision at lepton colliders?
  - Look at the "tails" of charged and neutral Drell-Yan lepton pairs

	universal form factor ($\mathcal{L}$)	contact operator ($\mathcal{L}'$)
W	$-\frac{\mathrm{W}}{4m_W^2}(D_\rho W^a_{\mu\nu})^2$	$-\frac{g_2^2\mathrm{W}}{2m_W^2}J_{L\,\mu}^{\,a}J_{L\,a}^{\,\mu}$
Y	$-\frac{\mathrm{Y}}{4m_W^2}(\partial_\rho B_{\mu\nu})^2$	$-\frac{g_1^2\mathrm{Y}}{2m_W^2}J_{Y\,\mu}J_Y^{\,\mu}$

$$P_N = \begin{bmatrix} \frac{1}{q^2} - \frac{t^2\mathrm{W}+\mathrm{Y}}{m_Z^2} & \frac{t\left((\mathrm{Y}+\hat{\mathrm{T}})c^2+s^2\mathrm{W}-\hat{\mathrm{S}}\right)}{(c^2-s^2)(q^2-m_Z^2)} + \frac{t(\mathrm{Y}-\mathrm{W})}{m_Z^2} \\ \star & \frac{1+\hat{\mathrm{T}}-\mathrm{W}-t^2\mathrm{Y}}{q^2-m_Z^2} - \frac{t^2\mathrm{Y}+\mathrm{W}}{m_Z^2} \end{bmatrix}$$

$$P_C = \frac{1+\left((\hat{\mathrm{T}}-\mathrm{W}-t^2\mathrm{Y})-2t^2(\hat{\mathrm{S}}-\mathrm{W}-\mathrm{Y})\right)/(1-t^2)}{(q^2-m_W^2)} - \frac{\mathrm{W}}{m_W^2},$$