Laboratoire Leprince-Ringuet

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CMS

Effective field theory results from CMS

A. Gilbert on behalf of the CMS Collaboration

Higgs Hunting | 17 September 2026

Introduction

- This talk will focus mostly on the SMEFT
  - First relevant operators at dimension-6
  - Warsaw basis: 2499 operators, but reduced via flavour assumptions

$$L_{\mathrm{EFT}} = L_{\mathrm{SM}} + \sum_i \cancel{\frac{C_i^{(5)}}{\Lambda}} \mathcal{O}_i^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_i \cancel{\frac{C_i^{(7)}}{\Lambda^3}} \mathcal{O}_i^{(7)} + \sum_i \frac{C_i^{(8)}}{\Lambda^4} \mathcal{O}_i^{(8)} + \dots$$

Lepton-number violating — Violates B-L

$\mathcal{O}_i$: operators = interaction terms at a given expansion order

C_i : operators = Wilson coefficients, free parameters

Operators involving bosonic fields

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar l_p e_r \varphi)$
$Q_{\widetilde G}$	$f^{ABC} \widetilde G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p u_r \widetilde\varphi)$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu\varphi)^\star (\varphi^\dagger D_\mu\varphi)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p d_r \varphi)$
$Q_{\widetilde W}$	$\varepsilon^{IJK} \widetilde W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar l_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar l_p \gamma^\mu l_r)$
$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\, \widetilde G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eB}	$(\bar l_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i \overleftrightarrow{D}^I_\mu \varphi)(\bar l_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uG}	$(\bar q_p \sigma^{\mu\nu} T^A u_r)\widetilde\varphi\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar e_p \gamma^\mu e_r)$
$Q_{\varphi\widetilde W}$	$\varphi^\dagger\varphi\, \widetilde W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar q_p \sigma^{\mu\nu} u_r)\tau^I \widetilde\varphi\, W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar q_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar q_p \sigma^{\mu\nu} u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i \overleftrightarrow{D}^I_\mu \varphi)(\bar q_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\, \widetilde B_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar q_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar u_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar q_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar d_p \gamma^\mu d_r)$
$Q_{\varphi\widetilde WB}$	$\varphi^\dagger \tau^I \varphi\, \widetilde W^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar q_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu \varphi)(\bar u_p \gamma^\mu d_r)$

4-fermion operators (most flavour general case)

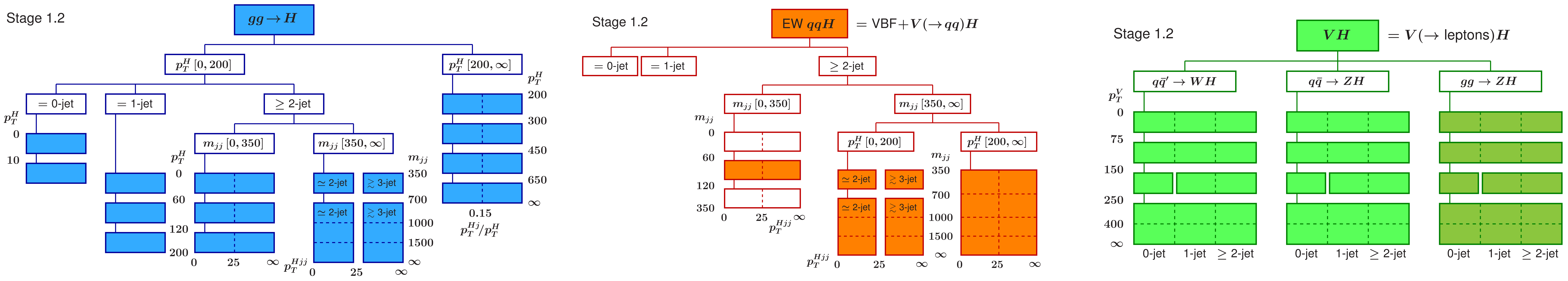
$(\bar LL)(\bar LL)$		$(\bar RR)(\bar RR)$		$(\bar LL)(\bar RR)$	
Q_{ll}	$(\bar l_p \gamma_\mu l_r)(\bar l_s \gamma^\mu l_t)$	Q_{ee}	$(\bar e_p \gamma_\mu e_r)(\bar e_s \gamma^\mu e_t)$	Q_{le}	$(\bar l_p \gamma_\mu l_r)(\bar e_s \gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar q_s \gamma^\mu q_t)$	Q_{uu}	$(\bar u_p \gamma_\mu u_r)(\bar u_s \gamma^\mu u_t)$	Q_{lu}	$(\bar l_p \gamma_\mu l_r)(\bar u_s \gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar q_p \gamma_\mu \tau^I q_r)(\bar q_s \gamma^\mu \tau^I q_t)$	Q_{dd}	$(\bar d_p \gamma_\mu d_r)(\bar d_s \gamma^\mu d_t)$	Q_{ld}	$(\bar l_p \gamma_\mu l_r)(\bar d_s \gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar l_p \gamma_\mu l_r)(\bar q_s \gamma^\mu q_t)$	Q_{eu}	$(\bar e_p \gamma_\mu e_r)(\bar u_s \gamma^\mu u_t)$	Q_{qe}	$(\bar q_p \gamma_\mu q_r)(\bar e_s \gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar l_p \gamma_\mu \tau^I l_r)(\bar q_s \gamma^\mu \tau^I q_t)$	Q_{ed}	$(\bar e_p \gamma_\mu e_r)(\bar d_s \gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar u_s \gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar u_p \gamma_\mu u_r)(\bar d_s \gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar q_p \gamma_\mu T^A q_r)(\bar u_s \gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar u_p \gamma_\mu T^A u_r)(\bar d_s \gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar d_s \gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar q_p \gamma_\mu T^A q_r)(\bar d_s \gamma^\mu T^A d_t)$

$(\bar LR)(\bar RL)$ and $(\bar LR)(\bar LR)$		B-violating	
Q_{ledq}	$(\bar l_p^j e_r)(\bar d_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q_{quqd}^{(1)}$	$(\bar q_p^j u_r)\varepsilon_{jk}(\bar q_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{quqd}^{(8)}$	$(\bar q_p^j T^A u_r)\varepsilon_{jk}(\bar q_s^k T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar l_p^j e_r)\varepsilon_{jk}(\bar q_s^k u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{lequ}^{(3)}$	$(\bar l_p^j \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar q_s^k \sigma^{\mu\nu} u_t)$		

- Why is the Higgs boson important for EFT?
  - Interactions with vector bosons and fermions provide unique sensitivity to wide set of operators
  - Interpretation of single and double H measurements
  - Important constraints when combined with other sectors

What do we want?

- Strongest **simultaneous** sensitivity to all **relevant** Wilson coefficients
  - Assume UV model leads to multiple $c_i \neq 0$
- Example: In the "topU3l" flavour assumption ($U(3)_l \times U(3)_e \times U(2)_q \times U(2)_u \times U(2)_d$) reduced to 182 operators
  - O(40) directly involve Higgs field, but pp→(H→)ff/VV processes studied sensitive to other operators (4-fermion, TGCs)
  - Need a sufficient set of observables (measuring inclusive rates not enough)
- Where to start?
  - State-of-the-art single Higgs combinations of all available production & decay channels
  - Analyses target "simplified template cross section" (STXS) fiducial cross sections (target specific prod. phase space)



Interpretation via STXS

Rep. Prog. Phys. 89 (2026) 087801

- Analyses aim to measure as many of these bins as possible in each final state

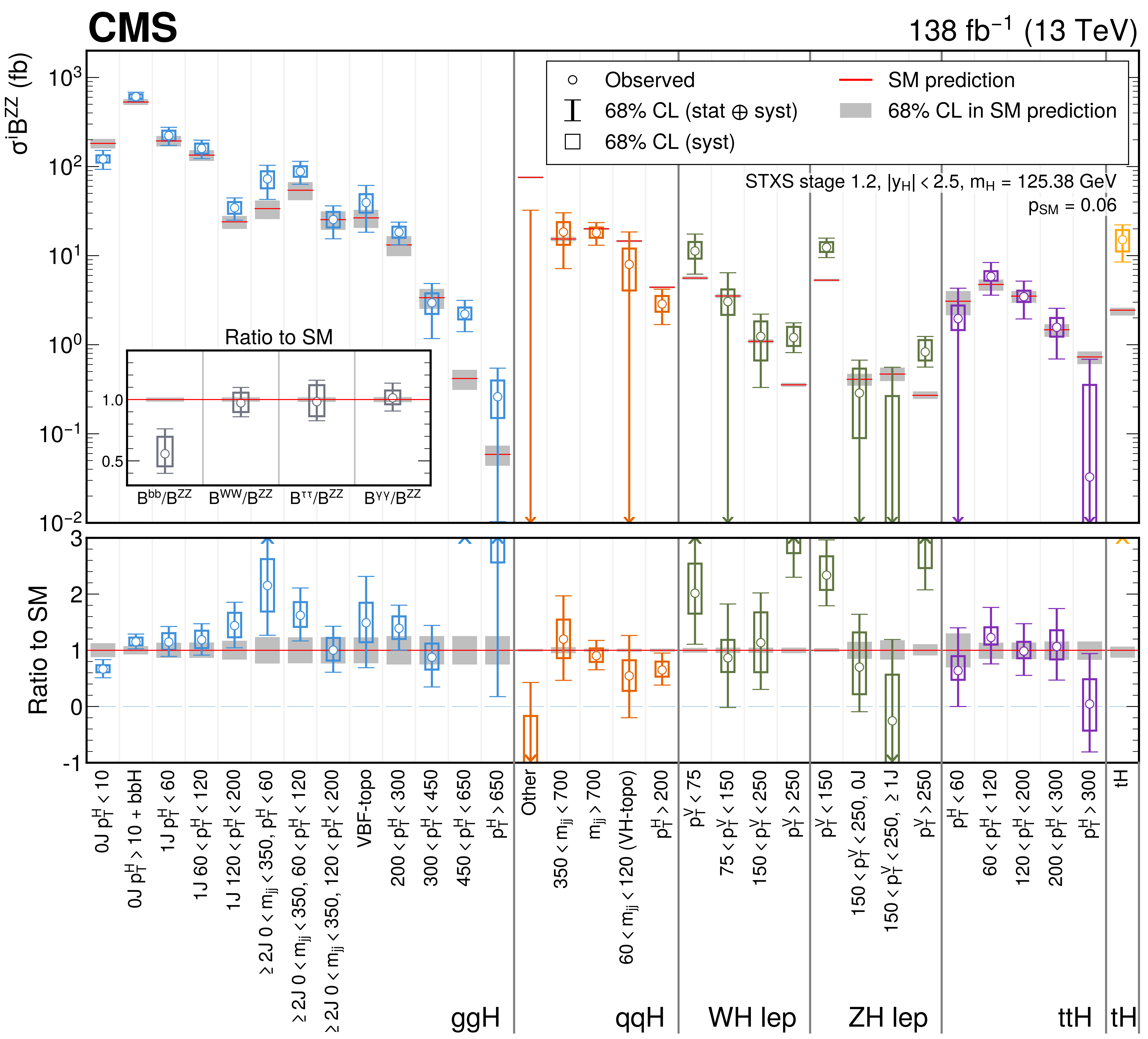
- Unfolding from reco. to gen. performed in the max. likelihood fit ⇒ parameterize each bin with WC dependence

- Some details:
  - Use the `topU3l` flavour assumptions
  - 43 (CMS) dim-6 operators (CP-even) considered
  - SMEFTsim for tree-level & propagator corrections
  - SMEFT@NLO for loop-level (ggF, gg→ZH), or analytic (H→γγ)
  - Parameterisation factorised into prod. and decay parts:
    - Some differences in linearisation wrt. ATLAS

$$\mu^{if}(\vec{c}) = \frac{[\sigma^i \mathcal{B}^f]_{\text{SMEFT}}}{[\sigma^i \mathcal{B}^f]_{\text{SM}}} = \mu^i_{\text{prod}}(\vec{c})\,\mu^f_{\text{partial}}(\vec{c})\,\mu^H(\vec{c})^{-1}$$

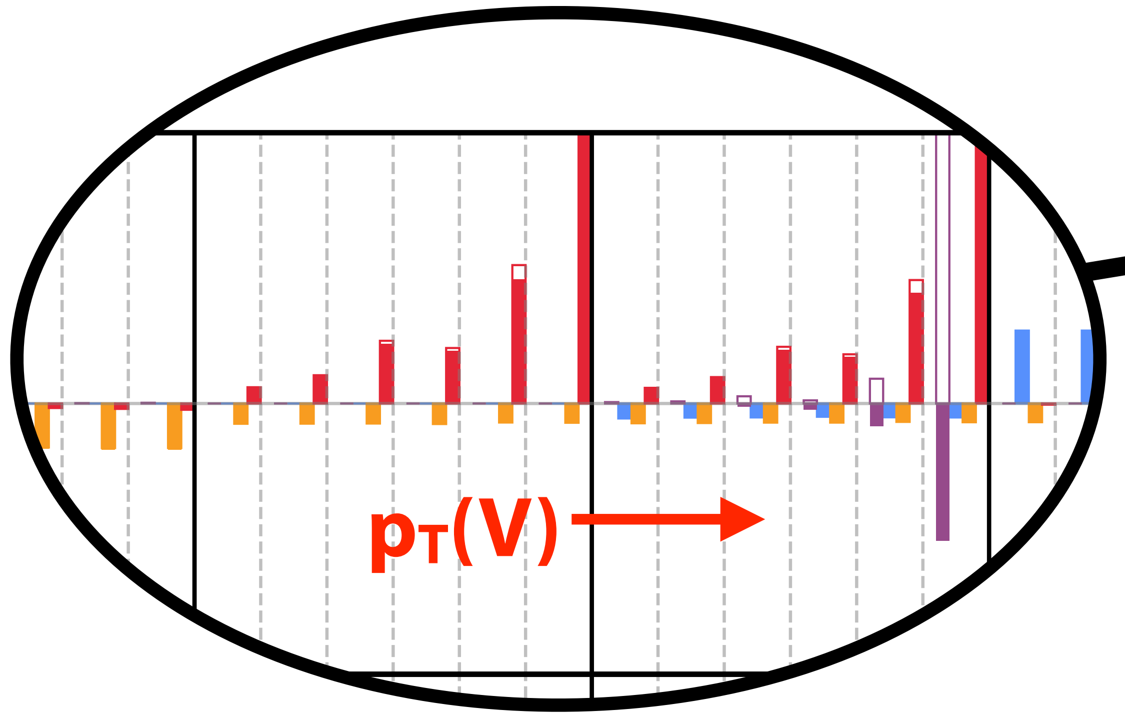
$$= \frac{\left(1+\sum_j A^i_j c_j + \sum_{jk} B^i_{jk} c_j c_k\right)\left(1+\sum_j A^f_j c_j + \sum_{jk} B^f_{jk} c_j c_k\right)}{\left(1+\sum_j A^H_j c_j + \sum_{jk} B^H_{jk} c_j c_k\right)}.$$

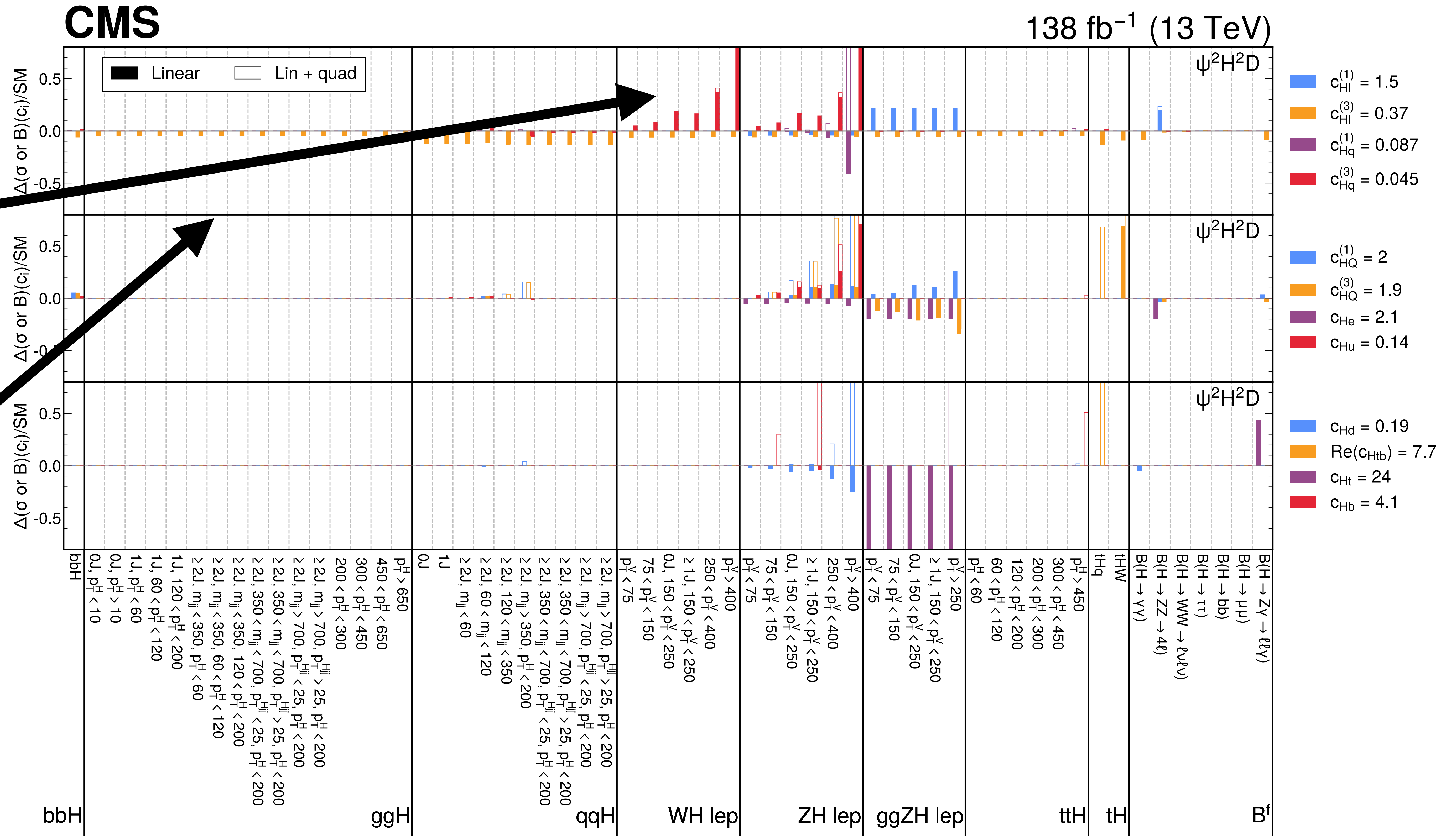
  - Possibility to consider "linear-only" fits (drop Λ^{-4} terms), or "linear + quadratic" (keeps terms up to Λ^{-4})



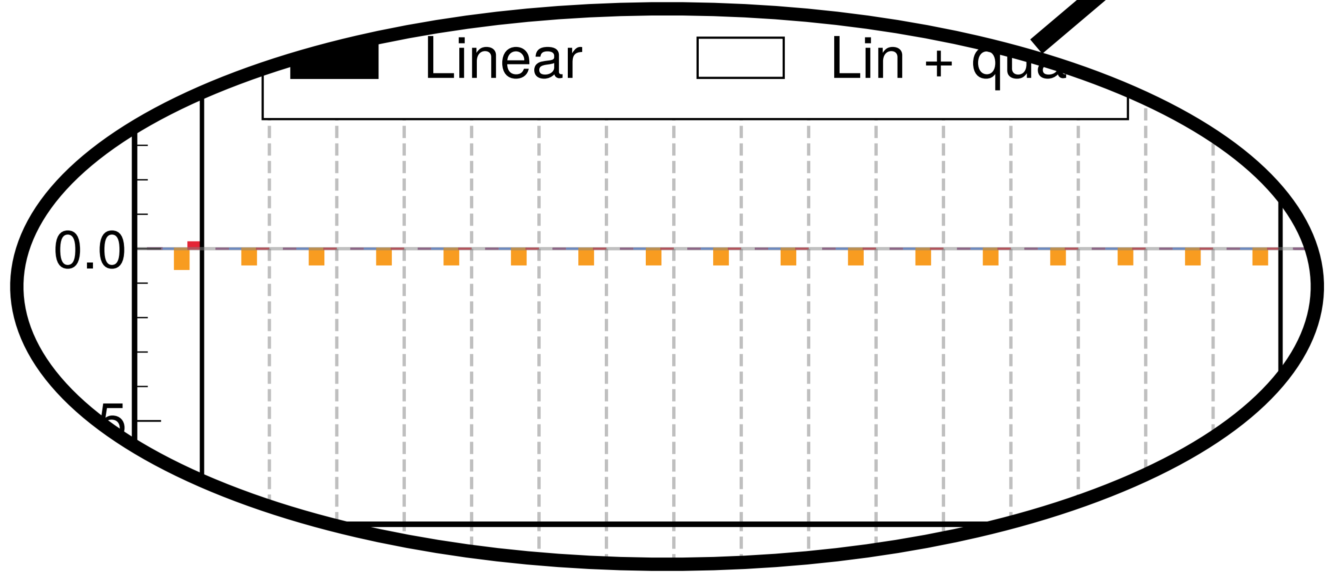
Interpretation via STXS

- Visualize the effect of operators on each cross section bin, and each B(H→XX)
- Some, eg. $c_{Hq}^{(3)}$ with clear energy growth





- Others, pure normalisation:

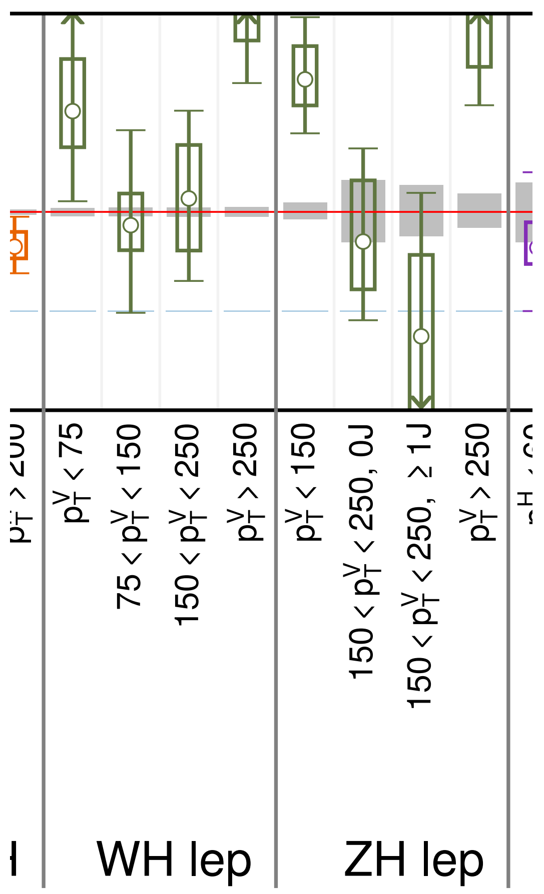


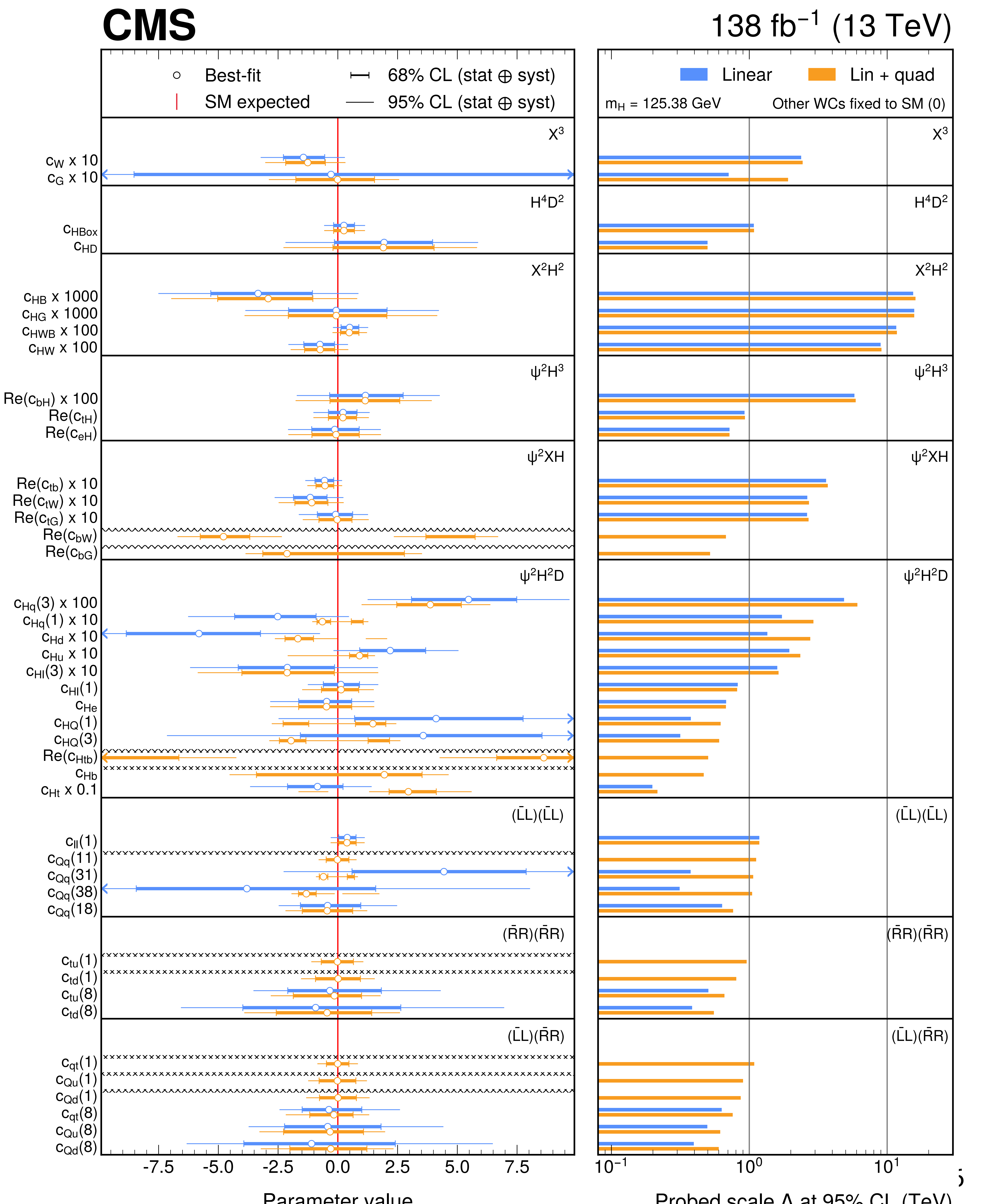
ggF bins

(*) Modified H propagator / modified Fermi constant

Interpretation via STXS

- Simultaneous fit of all WCs not possible ⇒ flat directions
  - Multiple WCs (or sets of combinations) with same effect
  - Minimum not uniquely defined
- CMS produces results w/ one non-zero Wilson coefficient at a time
- Constraints with and without the quadratic terms:
  - Useful as test of EFT validity
  - At Λ^{-4}, we miss effect of double dim-6 insertions (*), dim8-SM interference
  - (*) Somewhat addressed for Higgs by prod x decay factorisation
- In general, good agreement with SM
  - Exceptions: $c_{Hq}^{(3)}$ - p-value of 0.01
  - Caused by excess in high $p_T(V)$ bins for the STXS



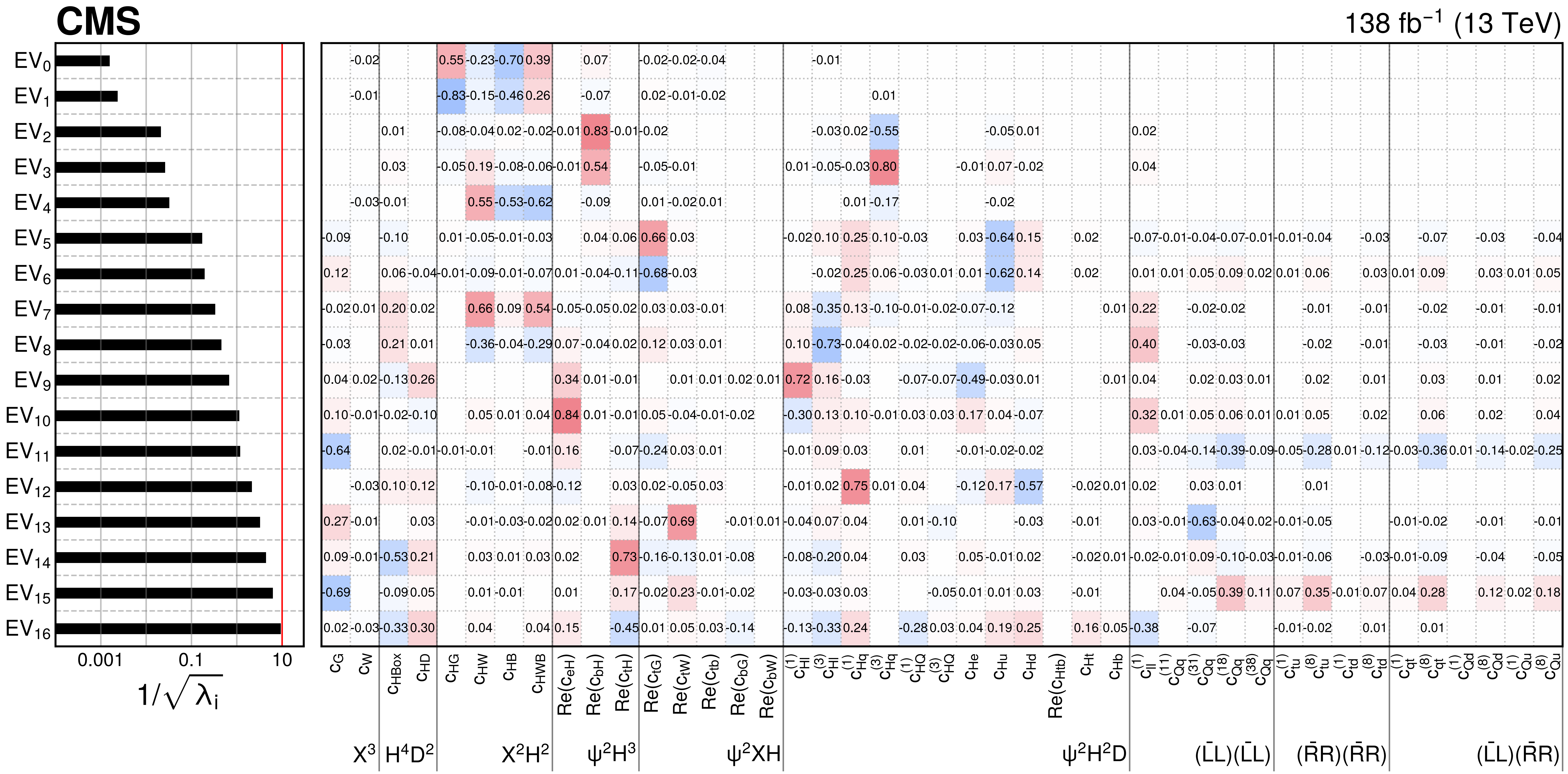


Solution: basis rotation

- Identify orthogonal directions in WC space using principle component analysis
  - Requires calculation of Hessian matrix for profile likelihood in terms of WCs
  - Built from STXS Hessian and translated using linear EFT parametrisation
  - Keep only those EVs with $\lambda > X$ (here $X = 0.01 \Rightarrow$ uncertainty of O(10))

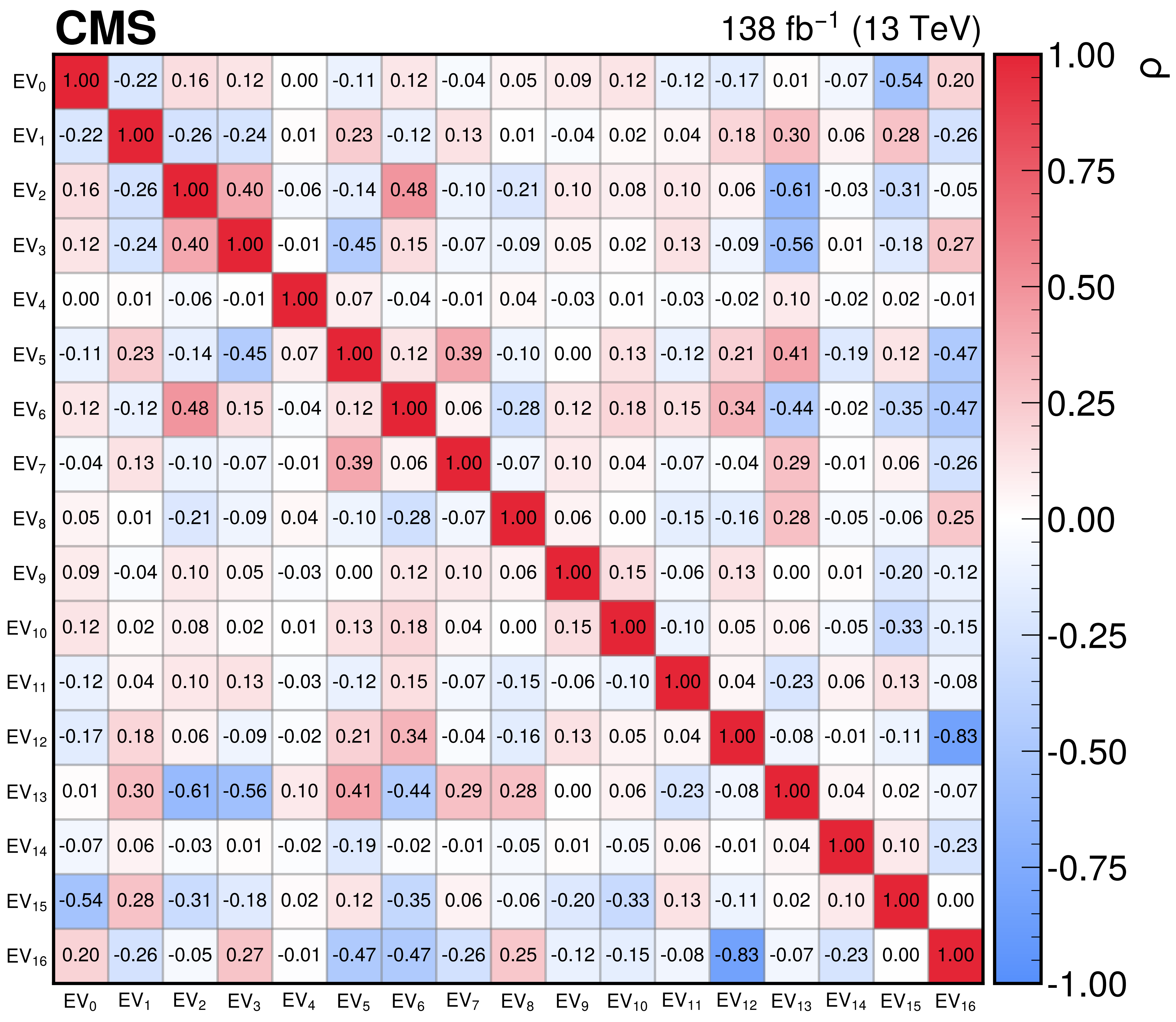
$$\widetilde{\mathcal{H}}_{\mathrm{SMEFT}} = \mathcal{T}^{T}\widetilde{\mathcal{H}}_{\mathrm{STXS}}\mathcal{T}$$

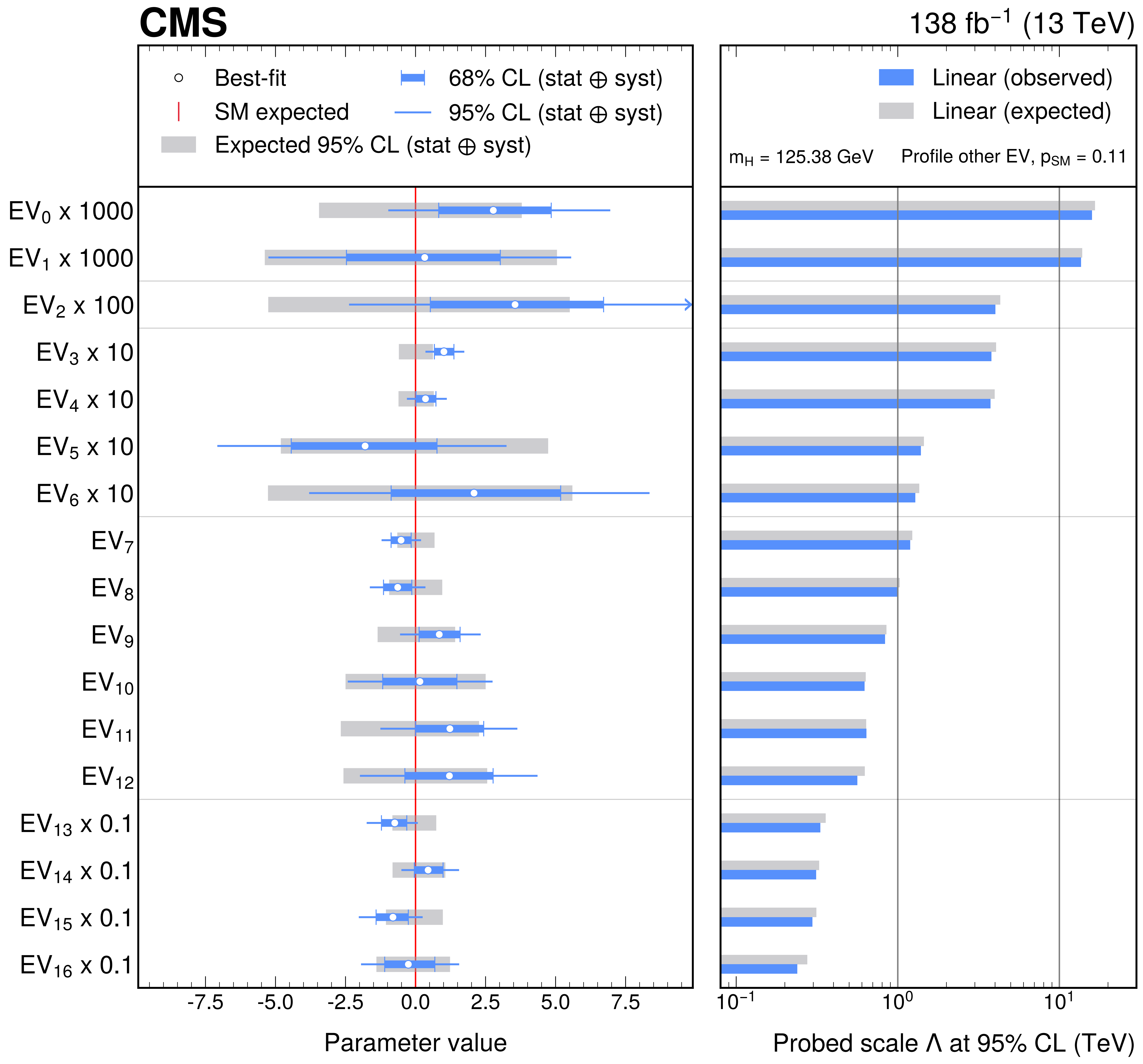
$$\mathcal{T}_{j}^{if} = A_{j}^{i} + A_{j}^{f} - A_{j}^{\mathrm{H}}$$



Results

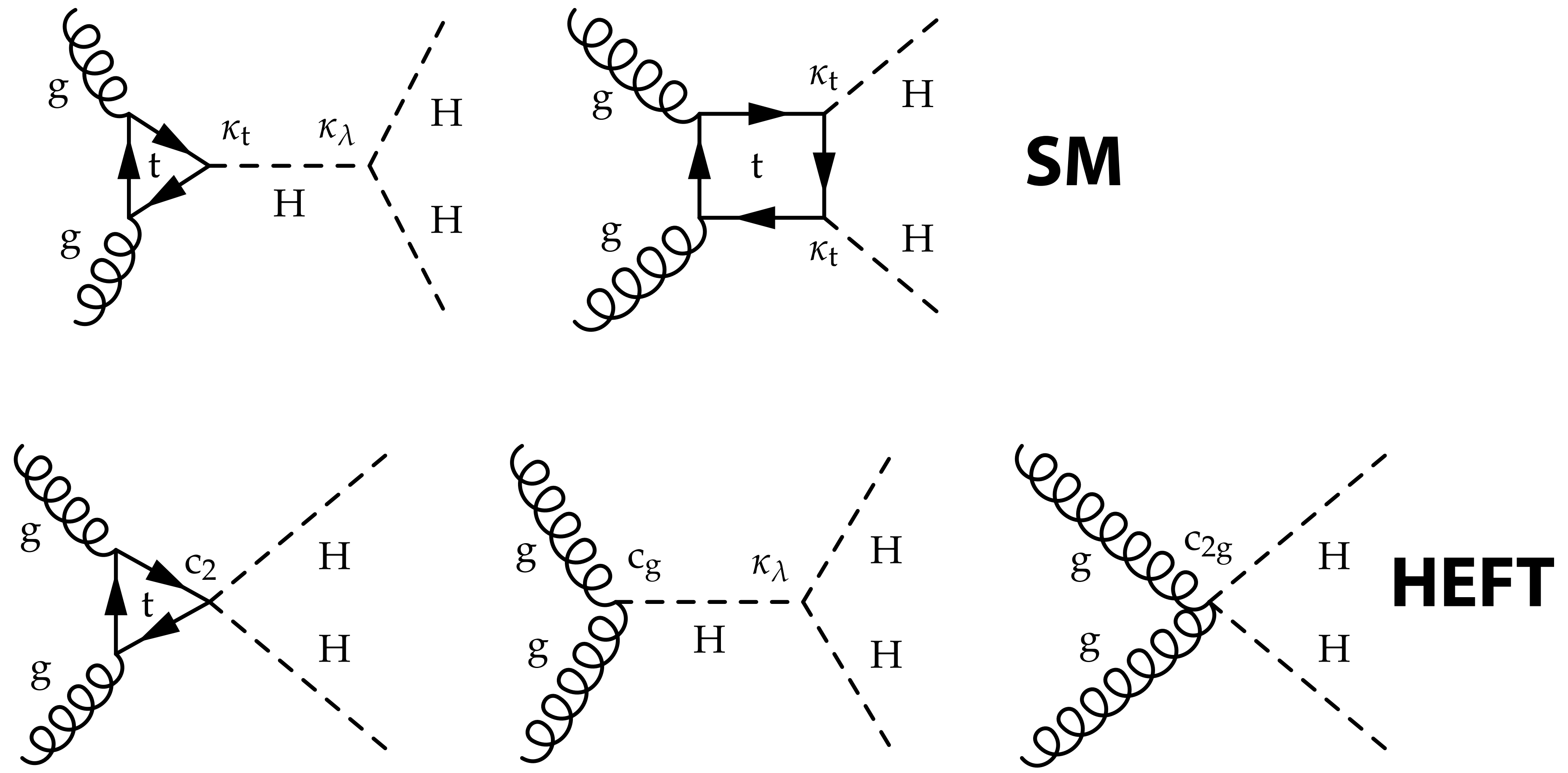
- Most correlations between EV parameters small (as expected)
- Some larger:
  - Some approximations with deriving Hessian
  - Use of Asimov at SM point vs data at non-SM

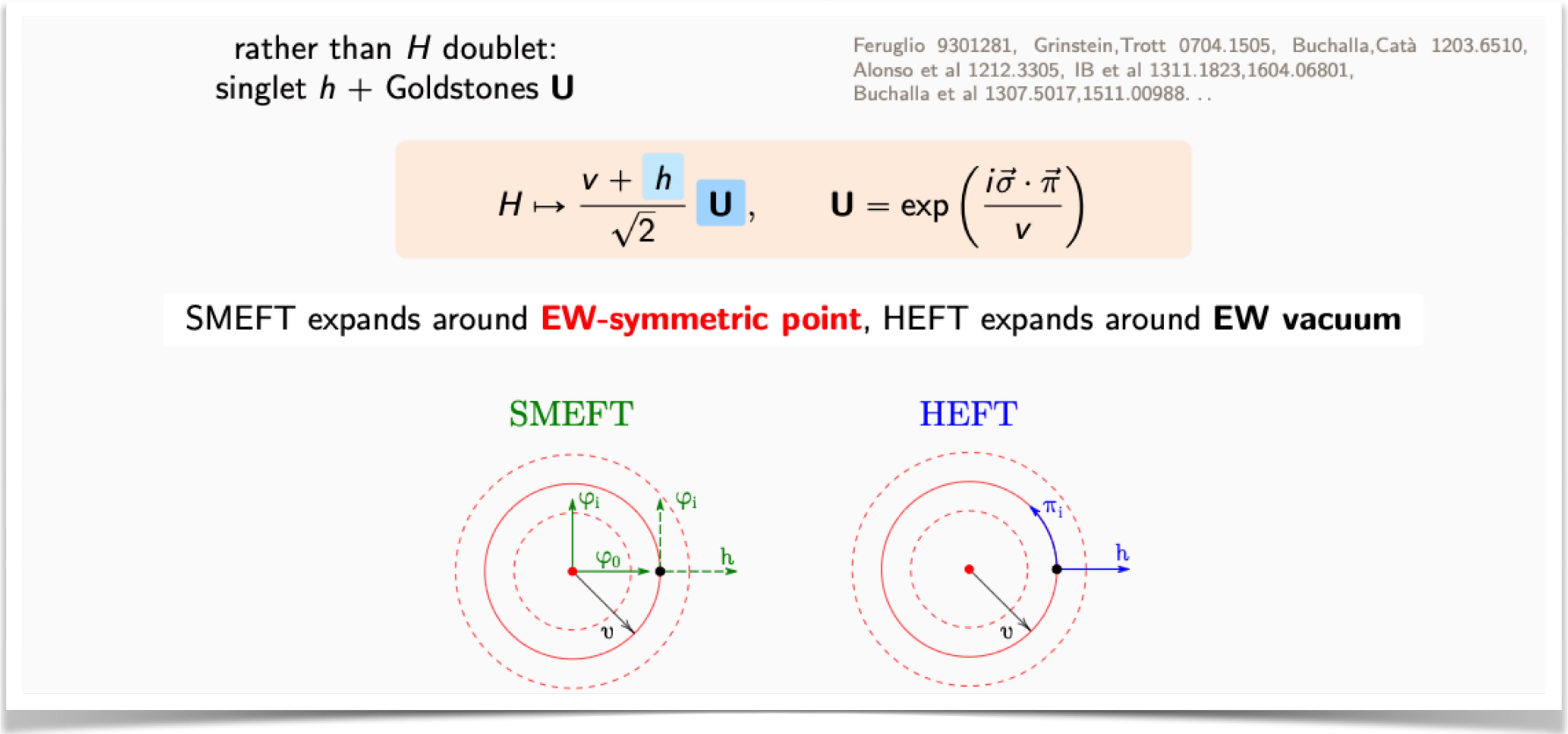




EFT results in di-Higgs production

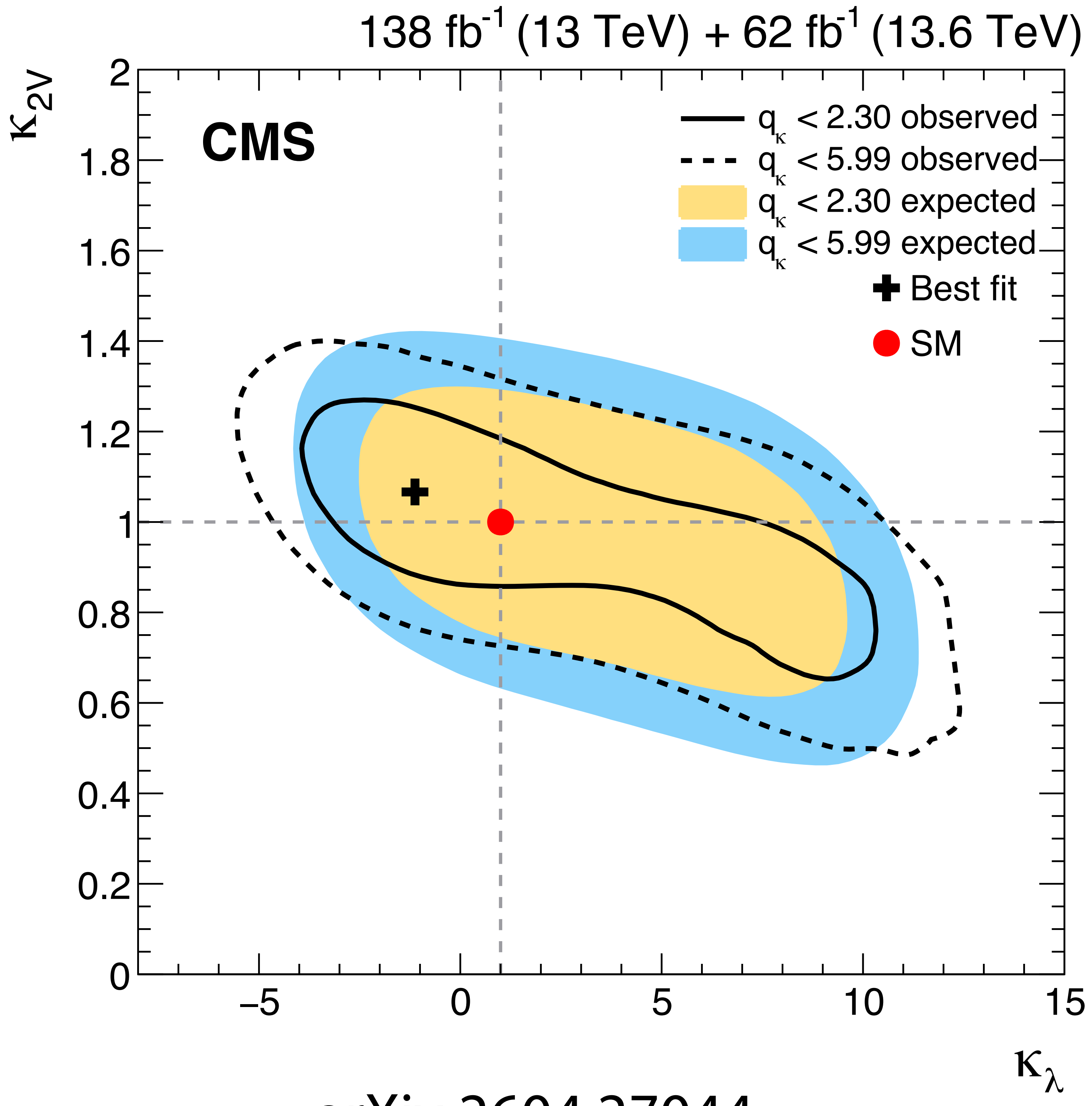
- HEFT: more general, weaker symmetry requirements
  - Some UV theories map to HEFT but not SMEFT
  - No assumption of a Higgs SU(2) doublet - rather single h + Goldstones U
- Mostly of interest in di-Higgs searches:





EFT results in di-Higgs production

- Recent results from CMS
- Updated HH→4b search (Run 2 + partial Run 3)
  - Most stringent constraints in 4b final state
  - Simultaneous constraint of k_λ and κ_{2V}
  - 30% improvement wrt Run 2

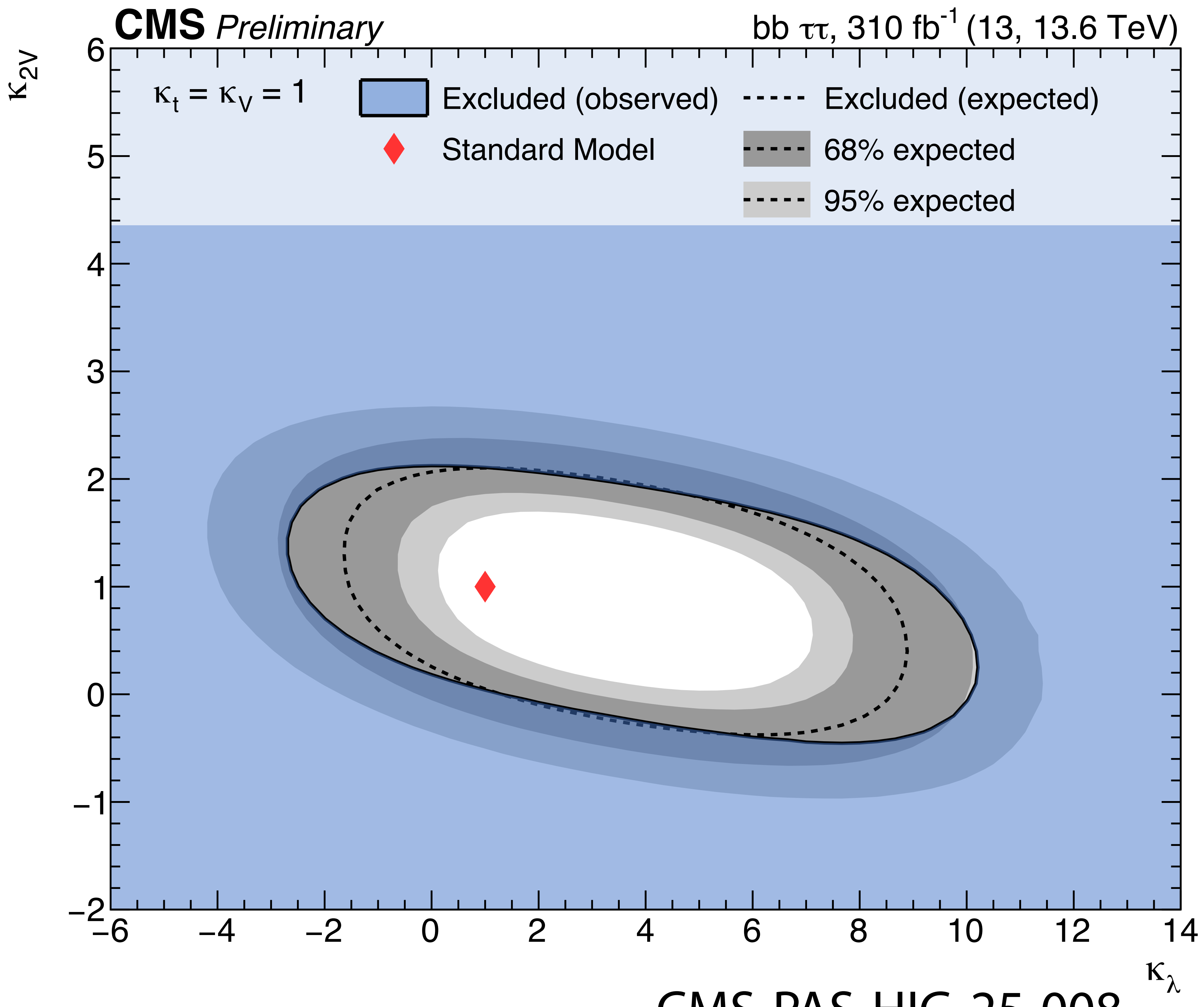


[arXiv:2604.27044]

95% CL:
$-2.5 < \kappa_\lambda < 9.4$
$0.02 < \kappa_{2V} < 2.1$

- HH→bbττ with 172 fb^{-1} Run 3 data, combined with Run 2
  - Improved trigger strategy (2τ + jet, parking)
  - Dedicated DNN for VBF selection
  - New DNN architecture
  - 20% improvement in sensitivity wrt lumi-scaled Run 2

95% CL:
$-2.5 < \kappa_\lambda < 9.4$
$0.02 < \kappa_{2V} < 2.1$

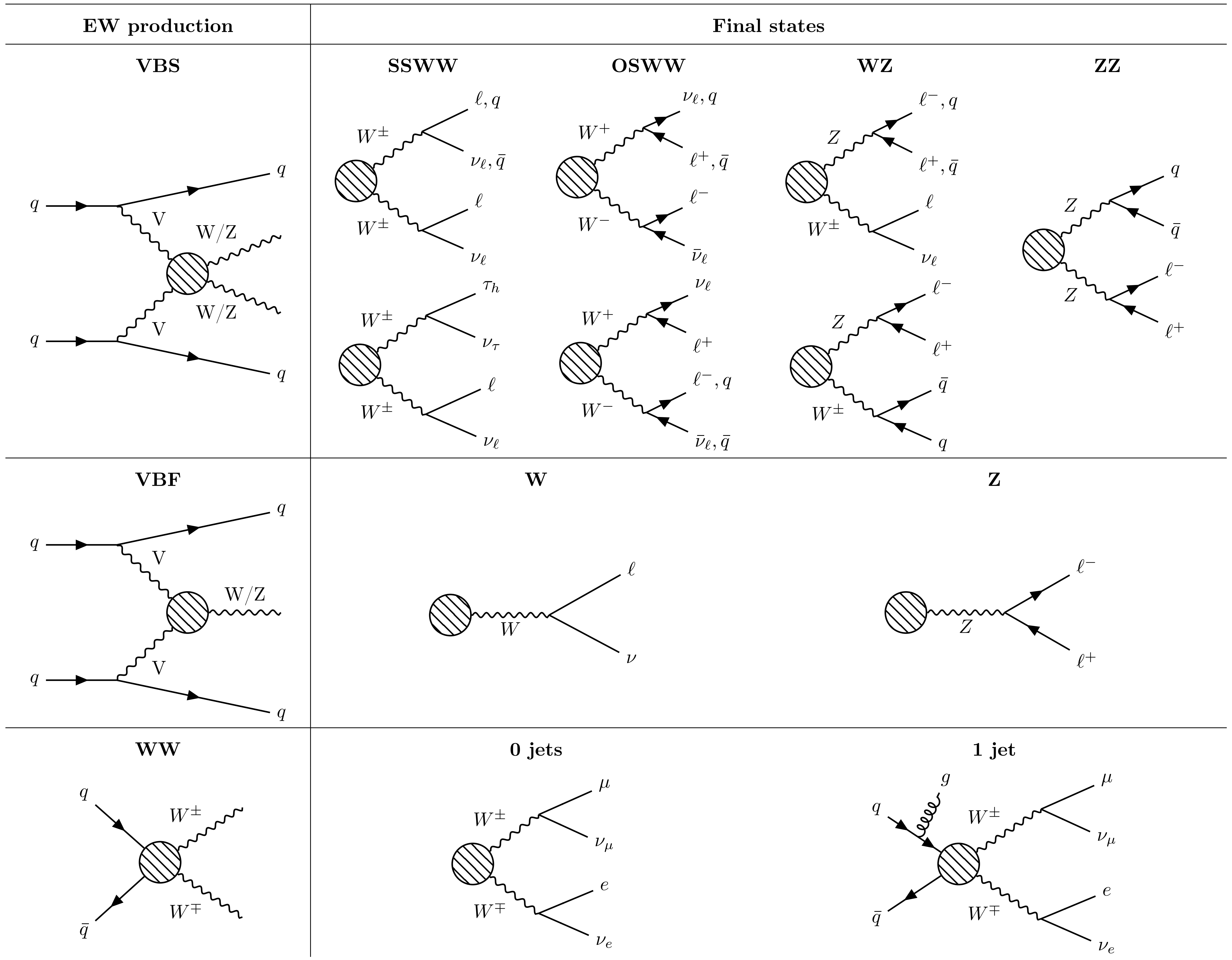


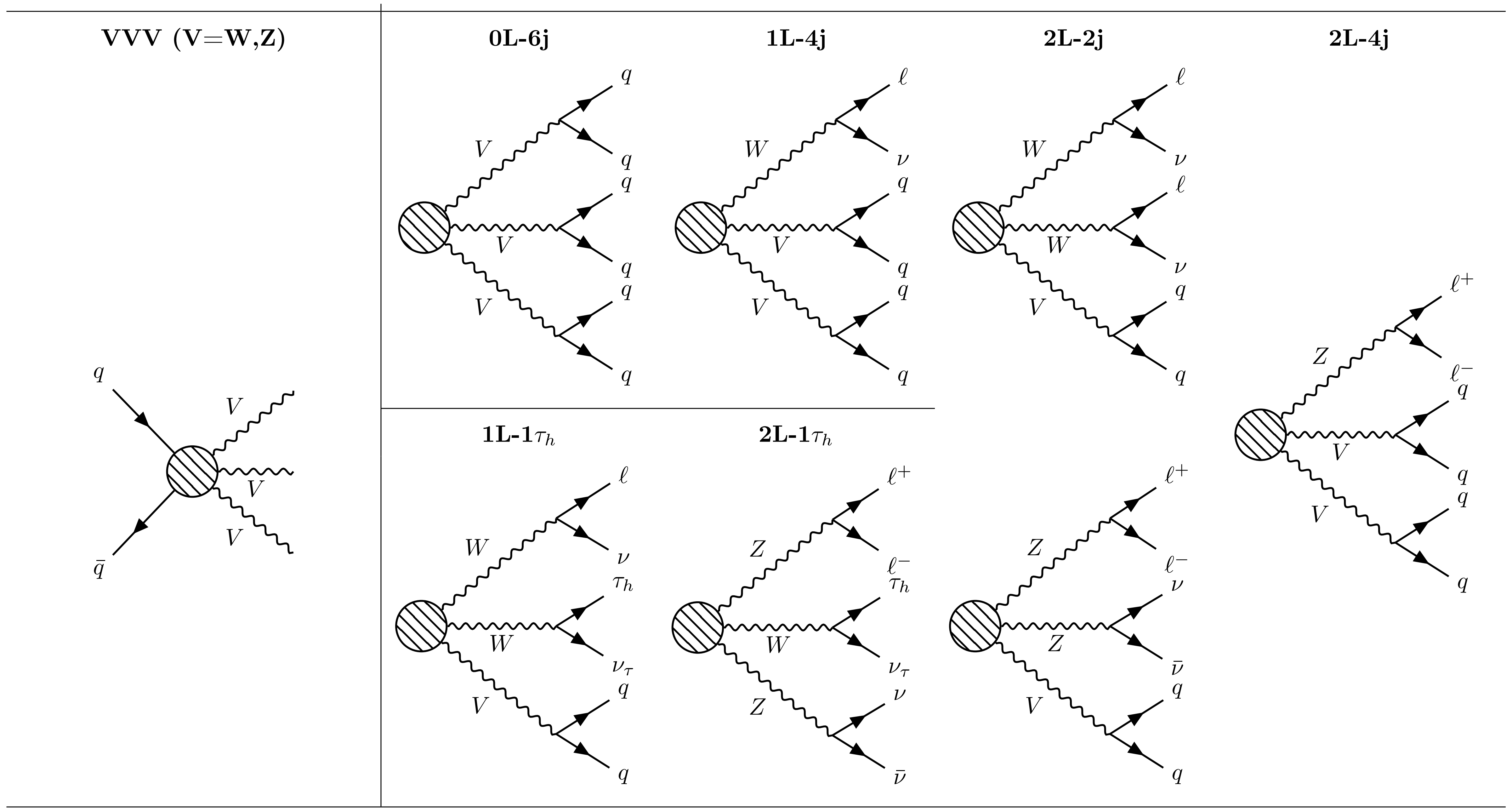
[CMS-PAS-HIG-25-008]

Stepping outside of Higgs…

CMS-PAS-SMP-25-002

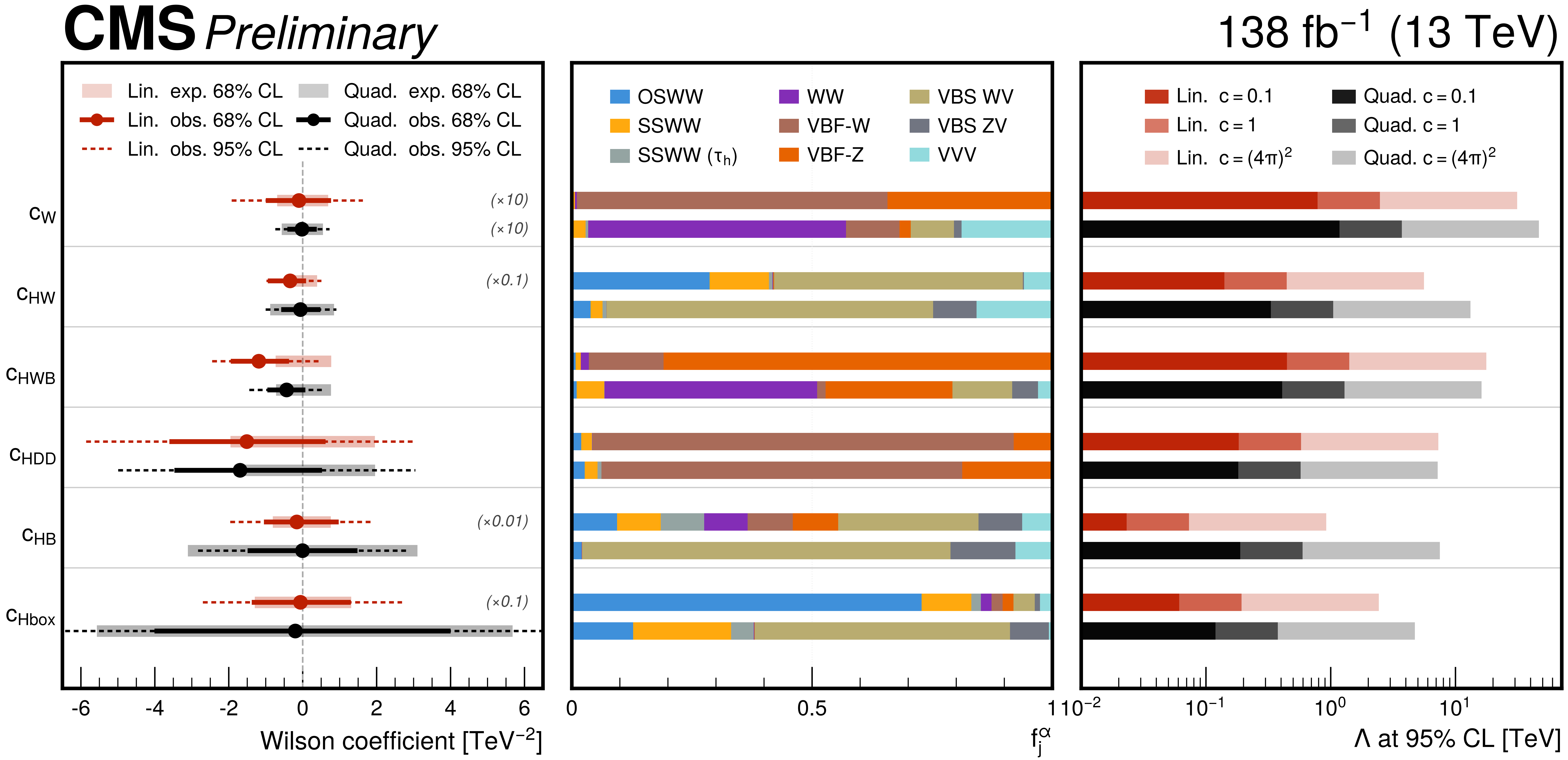
- Recent CMS combination of single and multi-boson production analyses that directly target EFT effects
- Relevant for the Higgs sector: All six operators probed also modify Higgs processes
  - Clear motivation for larger. cross-sector combinations, e.g. see CMS Higgs, EW, top, QCD combination: EPJC 86 (2026) 331





Stepping outside of Higgs…

- Recent CMS combination of single and multi-boson production analyses that directly target EFT effects
- Relevant for the Higgs sector: All six operators probed also modify Higgs processes
  - Clear motivation for larger. cross-sector combinations (see first CMS and ATLAS results on these)



Summary & outlook

- Excellent progress on exploiting EFT sensitivity in Higgs boson analyses
  - Longer term goal: full H + HH combination exploiting both production and decay information
  - Even longer term: merge with full combinations covering EW, top, QCD sectors
- We are generally not accounting for EFT effects in the background
  - Most relevant for channels with backgrounds from MC: VH(bb), $H\rightarrow WW$, $H\rightarrow\tau\tau$
  - Mitigation: use of control regions to float MC norm (less often shape)
  - Should really start doing this soon…
- Theory uncertainties in EFT predictions not yet incorporated
- Presentation of results:
  - Useful if all analyses can present version results in same format
  - 1-by-1 scans with both expected and observed 95% CL intervals should always be possible - good for benchmarking