EFT interpretations in the Higgs sector at CMS

DIS2024: 31st International Workshop on Deep Inelastic Scattering, Grenoble, France

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9 April 2024

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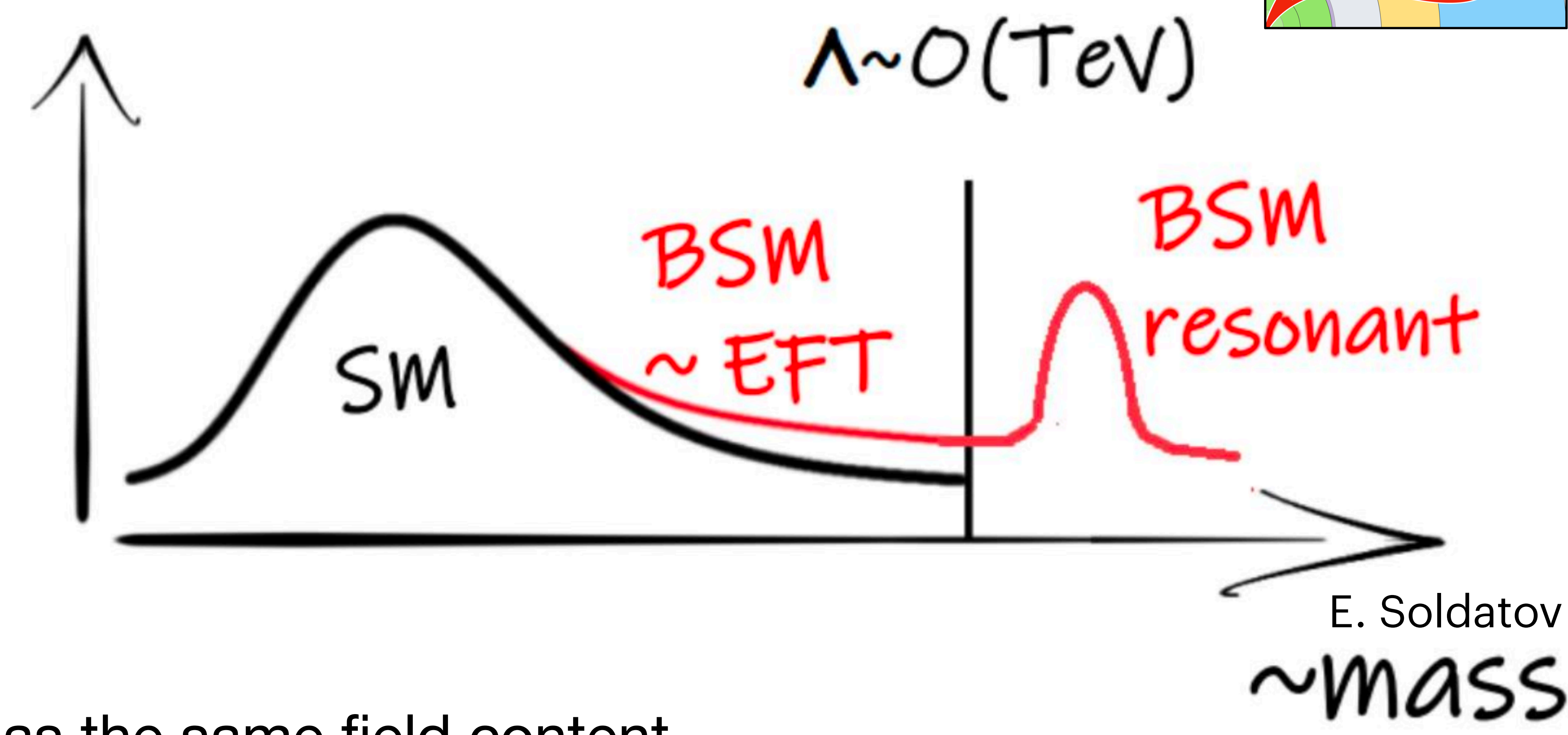
Introduction

Motivation

- No indication of New Physics at the LHC
- Increase in luminosity w\o increase in collisions energy strongly motivates indirect searches
  → increasing number of Higgs EFT measurements in CMS



Standard Model Effective Field Theory - SMEFT

In a nutshell, the new particles can be parameterised by an **EFT** where

→ the SM Lagrangian is supplemented by new operators and the theory has the same field content

General form

violate B-L number

$$\mathcal{L}_{\mathrm{eff}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i^{(5)}}{\Lambda} \mathcal{O}_i^{(5)} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_i \frac{c_i^{(7)}}{\Lambda^3} \mathcal{O}_i^{(7)} + \sum_i \frac{c_i^{(8)}}{\Lambda^4} \mathcal{O}_i^{(8)} + \cdots$$

where each $O_i^{(D)}$ is an $SU(3) \times SU(2) \times U(1)$ invariant operator and $c_i^{(D)}$ are called *Wilson coefficients* (WC) (if $c_i = 0 \rightarrow SM$) and Λ is the scale of the new physics (typically chosen as 1TeV). Heavy BSM states are integrated out.

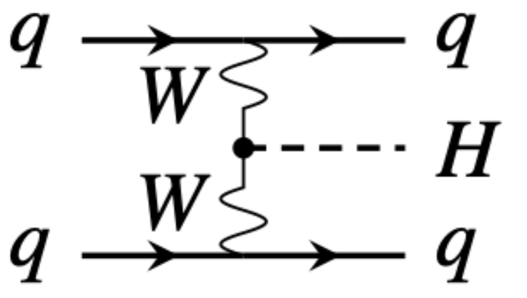
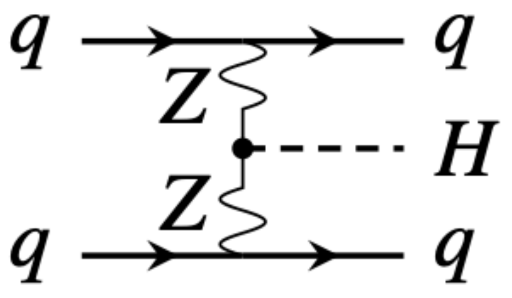
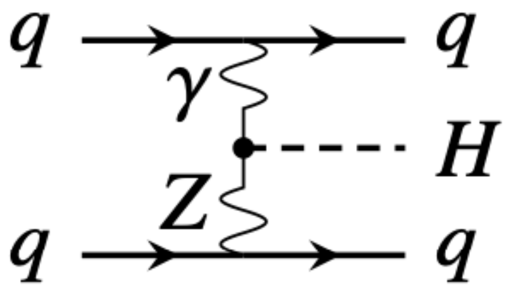
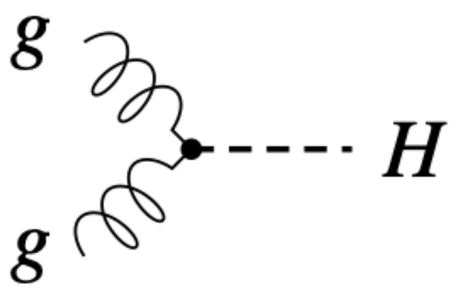
⇒ to parameterise observable effects - constraints of parameters = constraints on mass and couplings of new particles

Higgs sector in the SMEFT

- SMEFT introduces ~2500 CP-even operators at d=6 and ~37000 operators at d=8 …
- A set of operators generally used by CMS and ATLAS experiments: **Warsaw Basis** [link]

  → a parameterisation framework within the SMEFT, tailored for studying Higgs anomalous couplings (AC)

  → reduces the number of d=6 operators to 59, non-redundant

c_{HW}	$H^\dagger H\, W^I_{\mu\nu} W^{I\mu\nu}$		c_{HB}	$H^\dagger H\, B_{\mu\nu} B^{\mu\nu}$	
c_{HWB}	$H^\dagger \tau^I H\, W^I_{\mu\nu} B^{\mu\nu}$		c_{HG}	$H^\dagger H\, G^A_{\mu\nu} G^{A\mu\nu}$	

Some relevant EFT operators contributing to the Higgs production in the SMEFT [link]

- Observables: **Effective fractional cross section**

e.g. HVV scattering amplitude:

$$\mathcal{A}(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} p_1^2 + \kappa_2^{\mathrm{VV}} p_2^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2} \right] m_{\mathrm{V}1}^2 \epsilon_{\mathrm{V}1}^* \epsilon_{\mathrm{V}2}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2)\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2)\mu\nu}$$

$$f_{ai} = \frac{|a_i|^2 \sigma_i}{\sum_j |a_j|^2 \sigma_j} \,\mathrm{sign}\left(\frac{a_i}{a_1}\right)$$

→ convenient to measure the effective cross section ratios *f* rather than the anomalous couplings themselves, as most **uncertainties cancel in the ratio**.

HVV constraints in $H \rightarrow WW$ final state

Expanding the previous study into anomalous couplings (AC) within the same decay channel.

→ **Warsaw basis**

→ provide constraints on ACs at the HVV and Hgg vertices with dedicated categories targeting ggF, VBF, and VH

→ **MELA discriminant:** Output nodes distinguish kinematics between SM and BSM scenarios, and identifying interference between SM and BSM

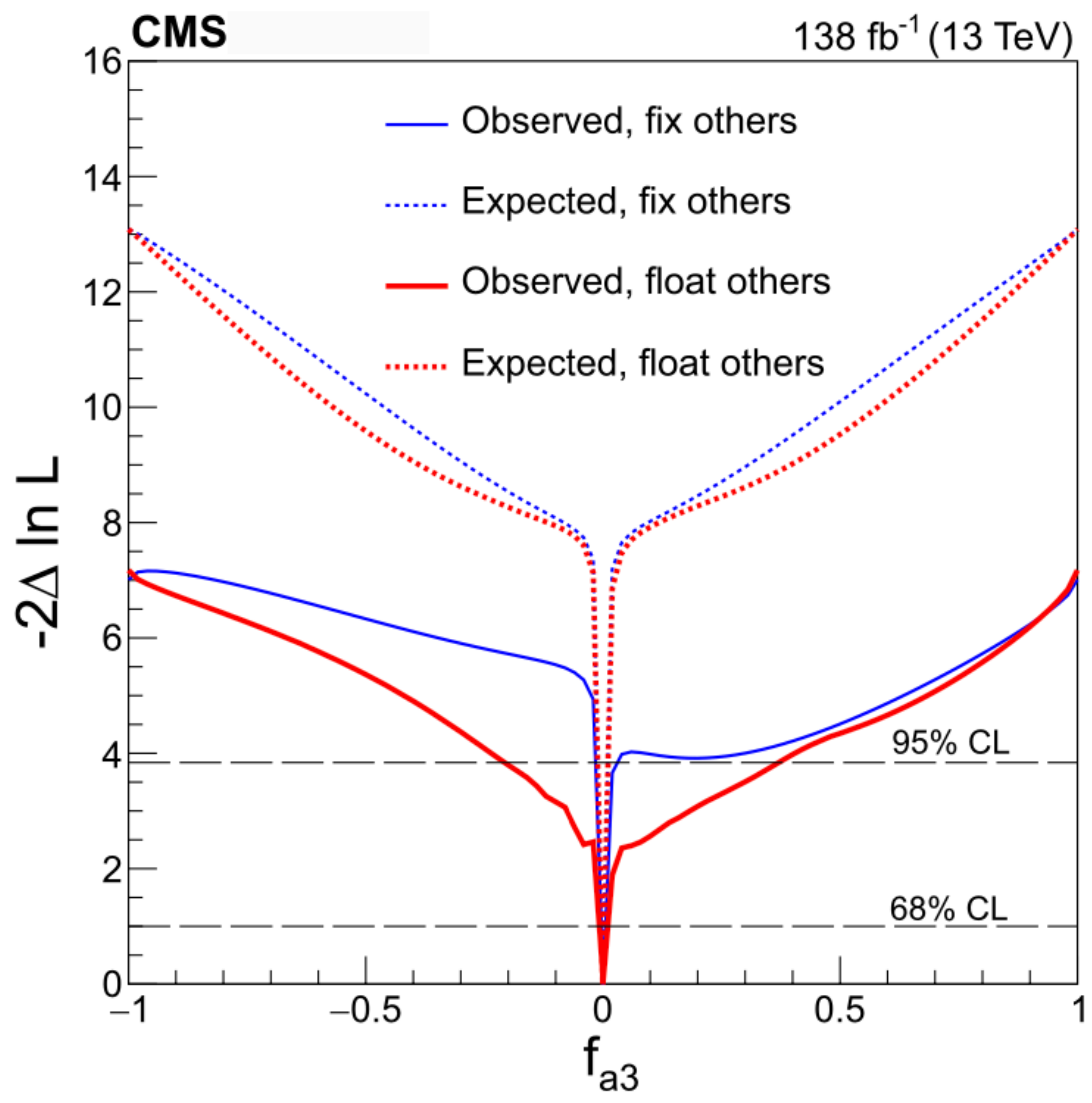
→ Two set of results with fixed or floating POI (parameter of interest) fitting

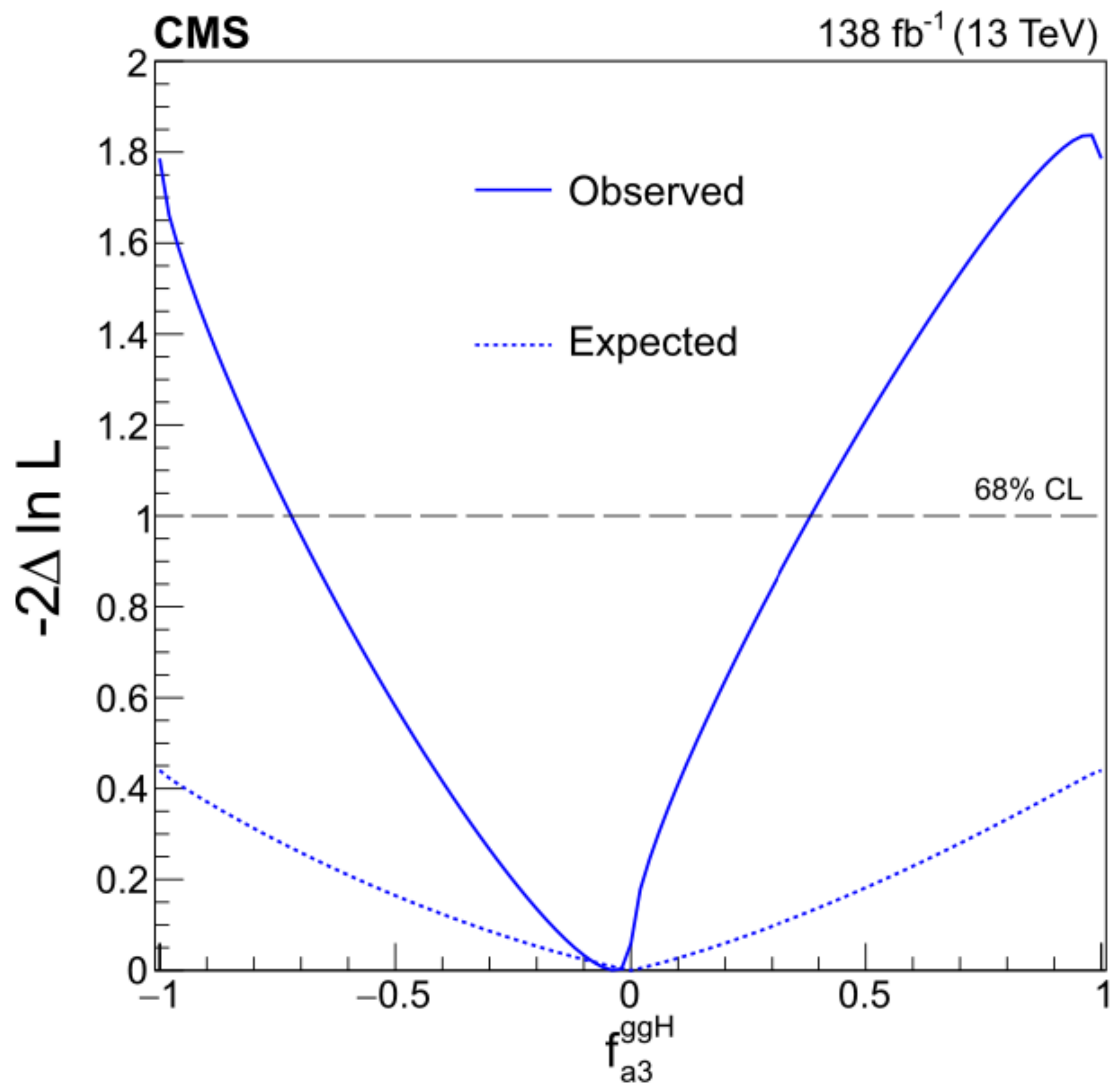
→ f_{a3} corresponds to the HVV vertex

CMS PAS HIG-22-008

→ Significant improvement in sensitivity/analysis coverage compared to full Run 1 analysis

Coupling	Observed	Expected
$c_{H\Box}$	$-0.76^{+1.43}_{-3.43}$	$0.00^{+1.37}_{-1.84}$
c_{HD}	$-0.12^{+0.93}_{-0.32}$	$0.00^{+0.43}_{-0.30}$
c_{HW}	$0.08^{+0.43}_{-0.87}$	$0.00^{+0.37}_{-0.48}$
c_{HWB}	$0.17^{+0.88}_{-1.79}$	$0.00^{+0.77}_{-0.96}$
c_{HB}	$0.03^{+0.13}_{-0.26}$	$0.00^{+0.11}_{-0.14}$
$c_{H\tilde{W}}$	$-0.26^{+0.67}_{-0.50}$	$0.00^{+0.48}_{-0.52}$
$c_{H\tilde{W}B}$	$-0.54^{+1.37}_{-1.03}$	$0.00^{+0.99}_{-1.07}$
$c_{H\tilde{B}}$	$-0.08^{+0.20}_{-0.15}$	$0.00^{+0.15}_{-0.16}$





$H \to \tau\tau$ Analysis

Several EFT vertices are targeted

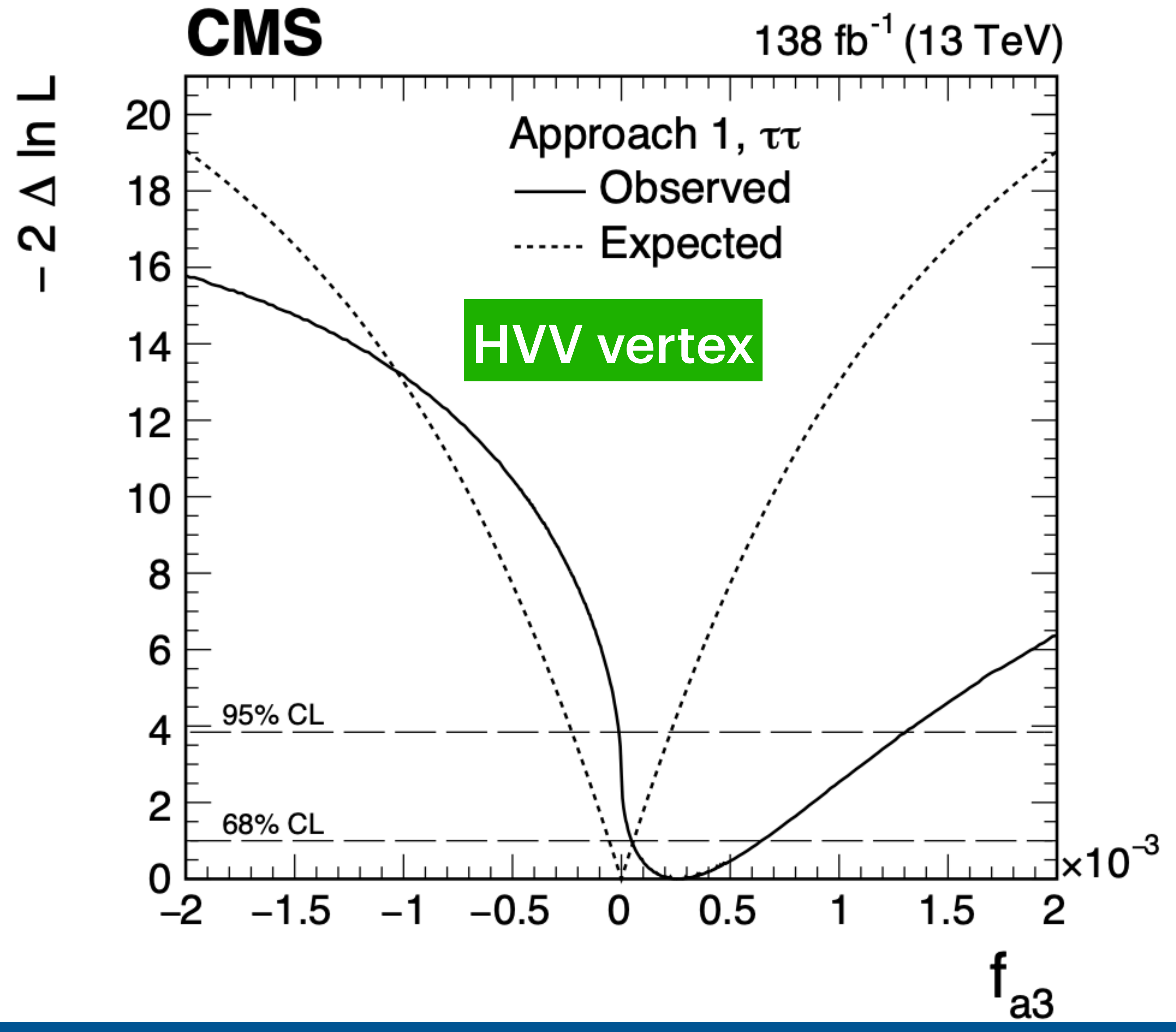
→ VBF production for HVV vertex ⇒ constrained using $H \to \tau\tau$ decay in VBF production

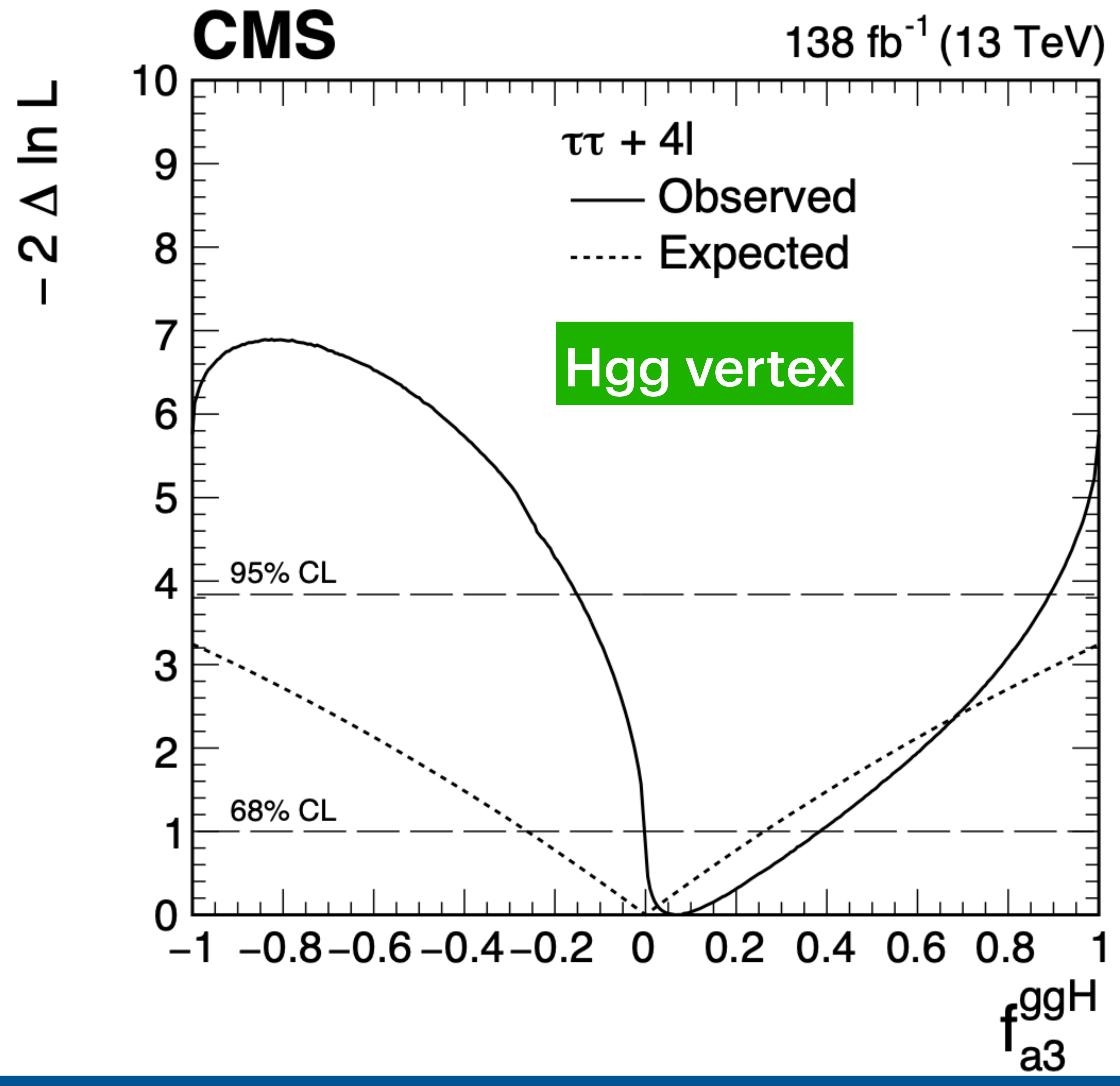
→ ggH production for Hgg vertex ⇒ constrained in combination of $H \to \tau\tau$ and $H \to Z \to 4l$ (on shell)

→ a **combination of neural networks** (to separate signal vs bkg) and **MELA** (to distinguish different signals) discriminants is used

→ extracted **effective fractional cross section**

Phys. Rev. D 108, 032013





$H \rightarrow \tau\tau$ Analysis (2)

Access to possible *CP*-violating effects in **H couplings to fermions** (Hff) in ggH production mode with

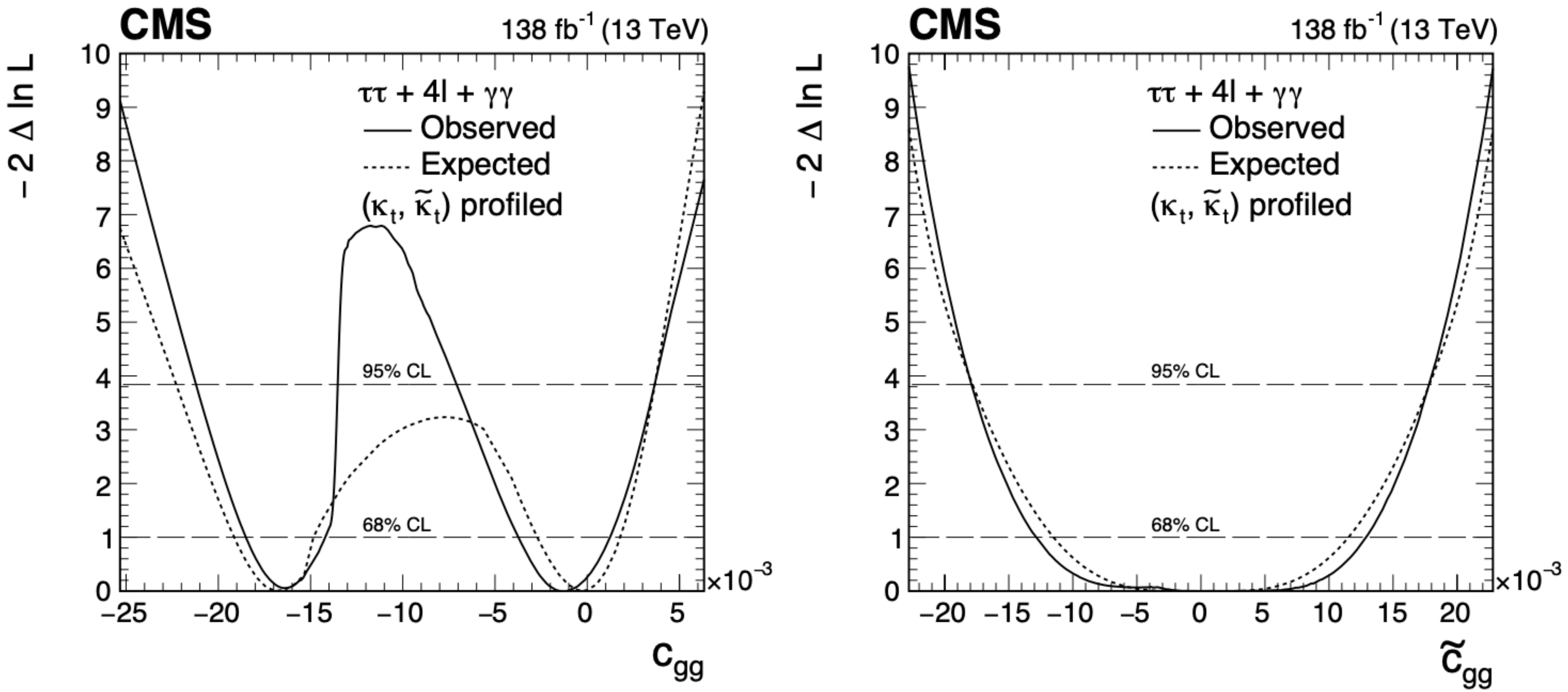
- H→ZZ
- ttH→γγ
- H→ττ

→ combination improves limits on anomalous couplings by around 25%

→ constraints on c_{gg} and CP-odd $\tilde{c}_{gg}$ operators are performed

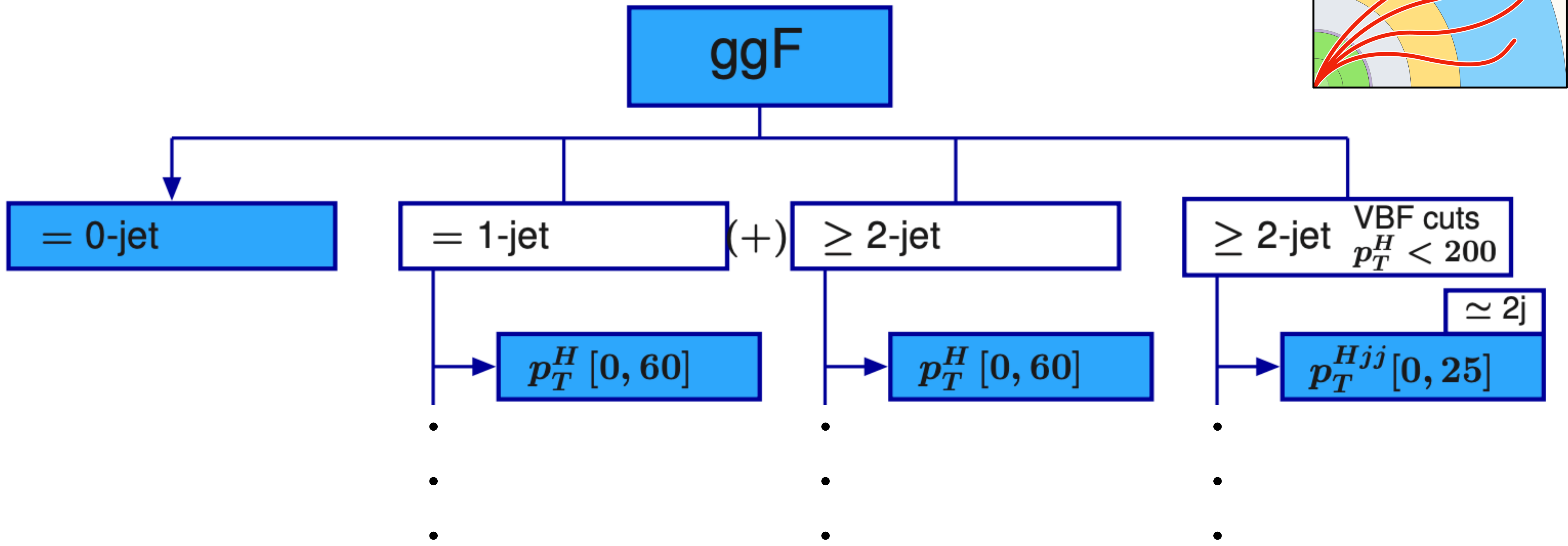
⇒ pure CP-odd hypothesis for Higgs coupling to gluons excluded with a significance of 2.4σ

Phys. Rev. D 108, 032013



UCLouvain CMS

STXS - Simplified Template Cross Sections [link]
maximise the sensitivity & minimize their theory dependence → introduce kinematic regions which help **isolate BSM effects,** subsequently serve as input for EFT interpretations.



$$\sigma_i^{EFT} = \sigma_i^{SM} + \sigma_i^{int} + \sigma_i^{BSM}$$

σ^{int} : the leading term in the EFT expansion ($\propto 1/\Lambda^2$)
σ^{BSM} : SM-independent term ($\propto 1/\Lambda^4$)

- a scaling function for each STXS bin i, which parameterises deviations in the cross section in terms of the HEL parameters

$$\mu = 1 + \frac{\sigma^{int}}{\sigma^{SM}} + \frac{\sigma^{BSM}}{\sigma^{SM}}$$

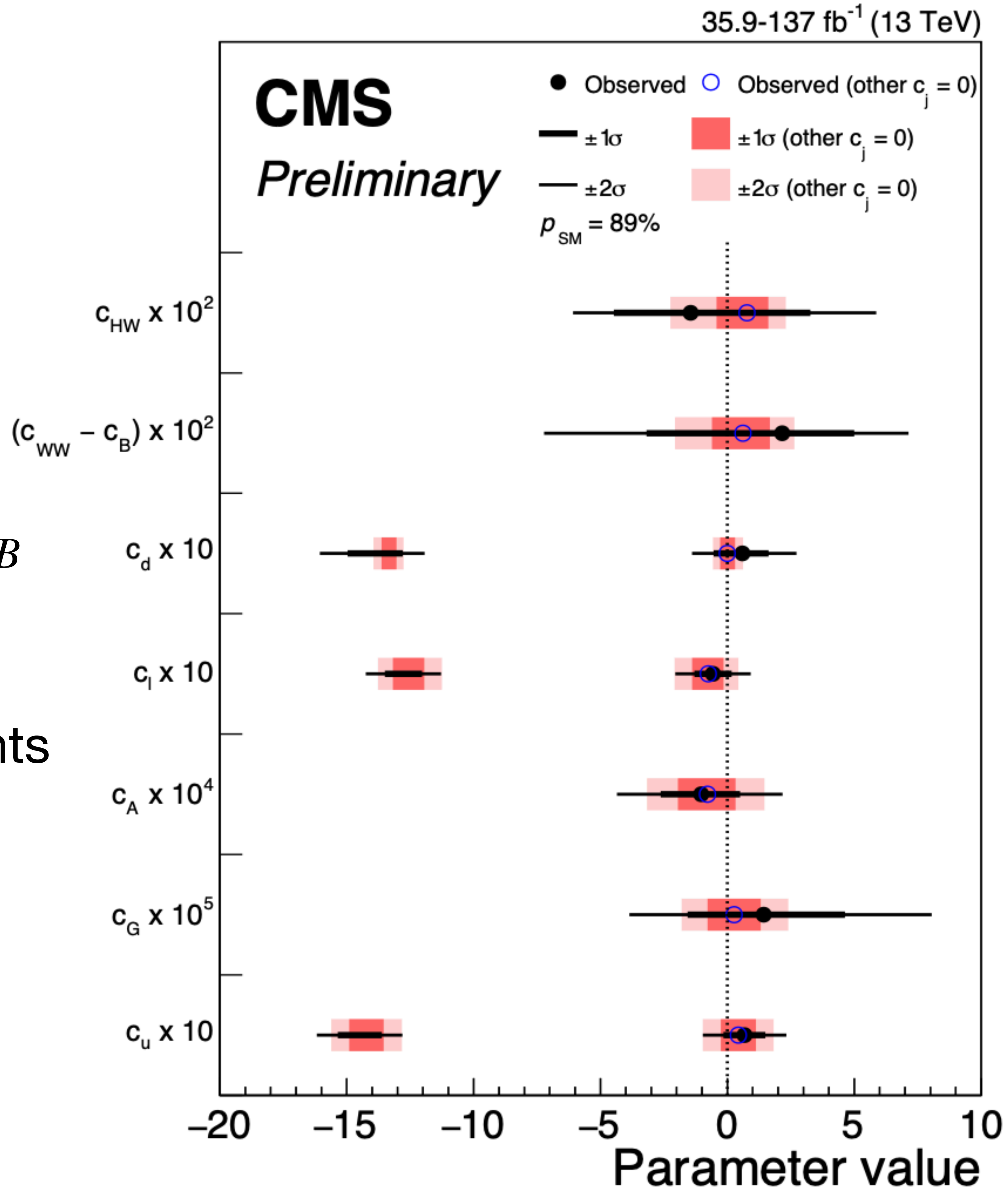
HEL Parameters	Definition	
$c_A \times 10^4$	$c_A = \frac{m_W^2}{g'^2} \frac{f_A}{\Lambda^2}$	c_A → H-V interaction, cp-odd
$c_G \times 10^5$	$c_G = \frac{m_W^2}{g_s^2} \frac{f_G}{\Lambda^2}$	c_G → H-gluon interactions
$c_u \times 10$	$c_u = -v^2 \frac{f_u}{\Lambda^2}$	c_u → H-up type quark
$c_d \times 10$	$c_d = -v^2 \frac{f_d}{\Lambda^2}$	c_d → H-down type quarks
$c_\ell \times 10$	$c_\ell = -v^2 \frac{f_\ell}{\Lambda^2}$	c_l → H-charged leptons
$c_{HW} \times 10^2$	$c_{HW} = \frac{m_W^2}{2g} \frac{f_{HW}}{\Lambda^2}$	c_{HW} →H-V interactions
$(c_{WW} - c_B) \times 10^2$	$c_{WW} = \frac{m_W^2}{g} \frac{f_{WW}}{\Lambda^2}$, $c_B = \frac{2m_W^2}{g'} \frac{f_B}{\Lambda^2}$	$c_{WW} - c_B$ →H-V, cp-even

EFT interpretation with STXS - CMS

CMS PAS HIG-19-005

- Partial Run2 combination **in STXS framework**
- Analyses included:
  - $H \rightarrow \gamma\gamma, 4l, l\nu l\nu, \tau\tau$
  - $ttH \rightarrow multilepton$
- EFT couplings extracted in HEL
- Measurement
  - $c_G, c_A, c_u, c_d, c_l, c_{HW}, c_{WW}, c_B$
  - c_{WW} and c_B are fit together
  - all freely-floating Wilson coefficients
  - and profiling one at a time

⇒ Results consistent with SM !



Correlations are observed

- in H−V vertices, c_{HW} and $c_{WW} - c_B$
  → limited differential information on VH production
- c_G and several others
  → ggH depends only on c_G due to LO implementation used, constraining it by the rate

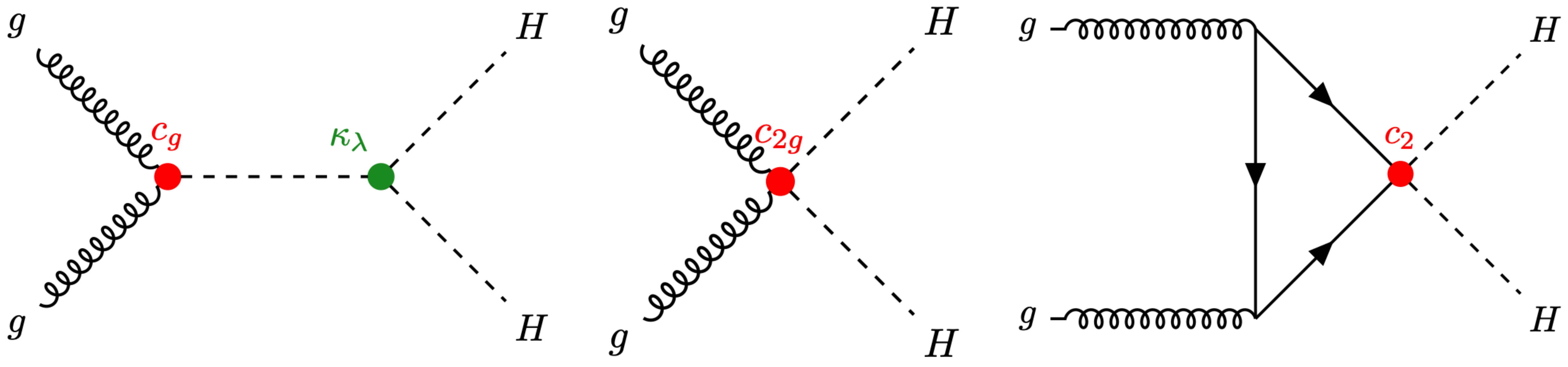
CMS *Preliminary* 35.9-137 fb^{-1} (13 TeV)

	c_u x 10	c_G x 10^5	c_A x 10^4	c_l x 10	c_d x 10	(c_{WW} − c_B) x 10^2	c_{HW} x 10^2
c_u x 10	1.00	0.42	0.03	-0.02	0.37	0.29	-0.30
c_G x 10^5	0.42	1.00	-0.01	0.08	0.85	0.50	-0.54
c_A x 10^4	0.03	-0.01	1.00	-0.32	-0.32	-0.09	-0.03
c_l x 10	-0.02	0.08	-0.32	1.00	0.19	-0.15	0.23
c_d x 10	0.37	0.85	-0.32	0.19	1.00	0.64	-0.60
(c_{WW} − c_B) x 10^2	0.29	0.50	-0.09	-0.15	0.64	1.00	-0.94
c_{HW} x 10^2	-0.30	-0.54	-0.03	0.23	-0.60	-0.94	1.00

ρ (color scale: −1 to 1)

EFT Interpretations in Double Higgs Analyses

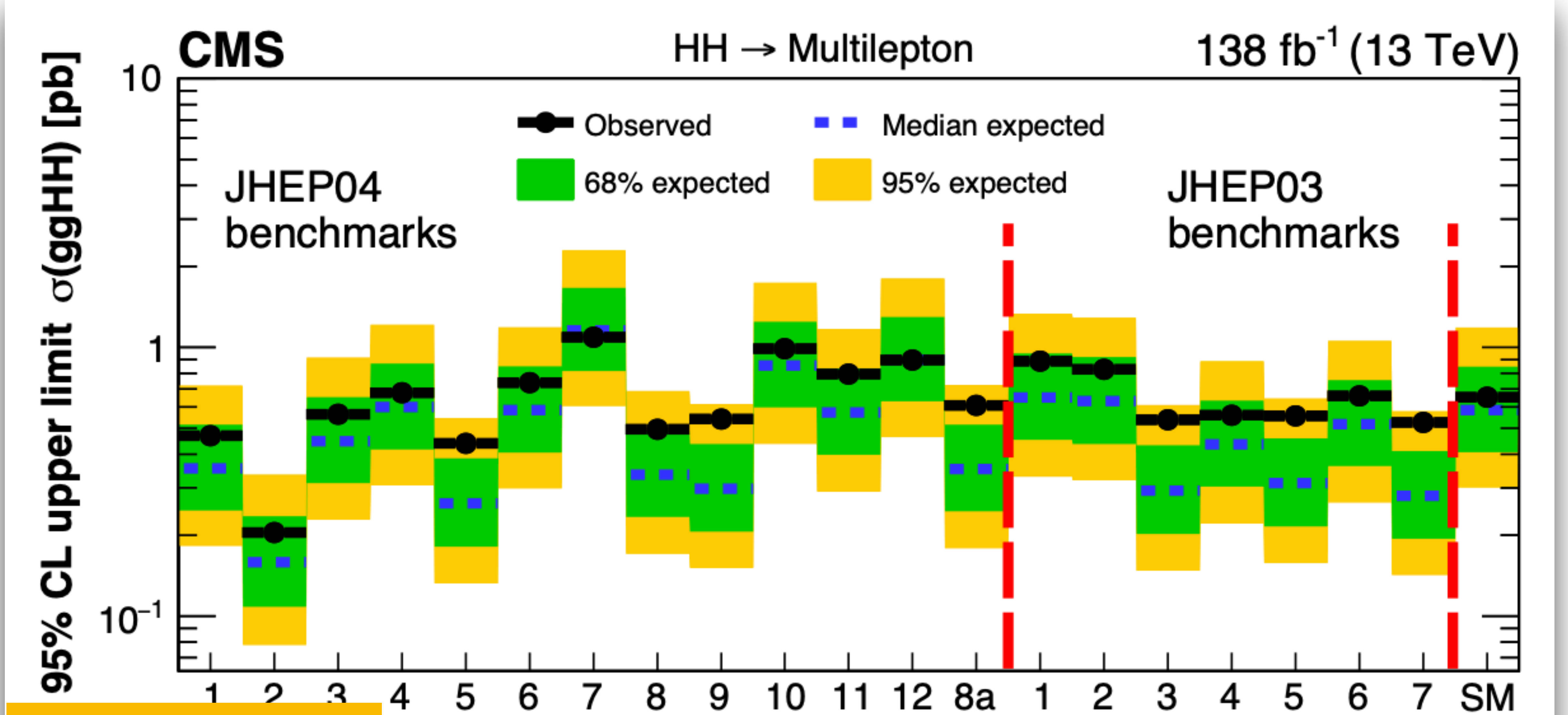
HEFT: Multiple benchmark models of coupling strengths and modifiers across the dim-6
→ maximum distinctions across different benchmarks



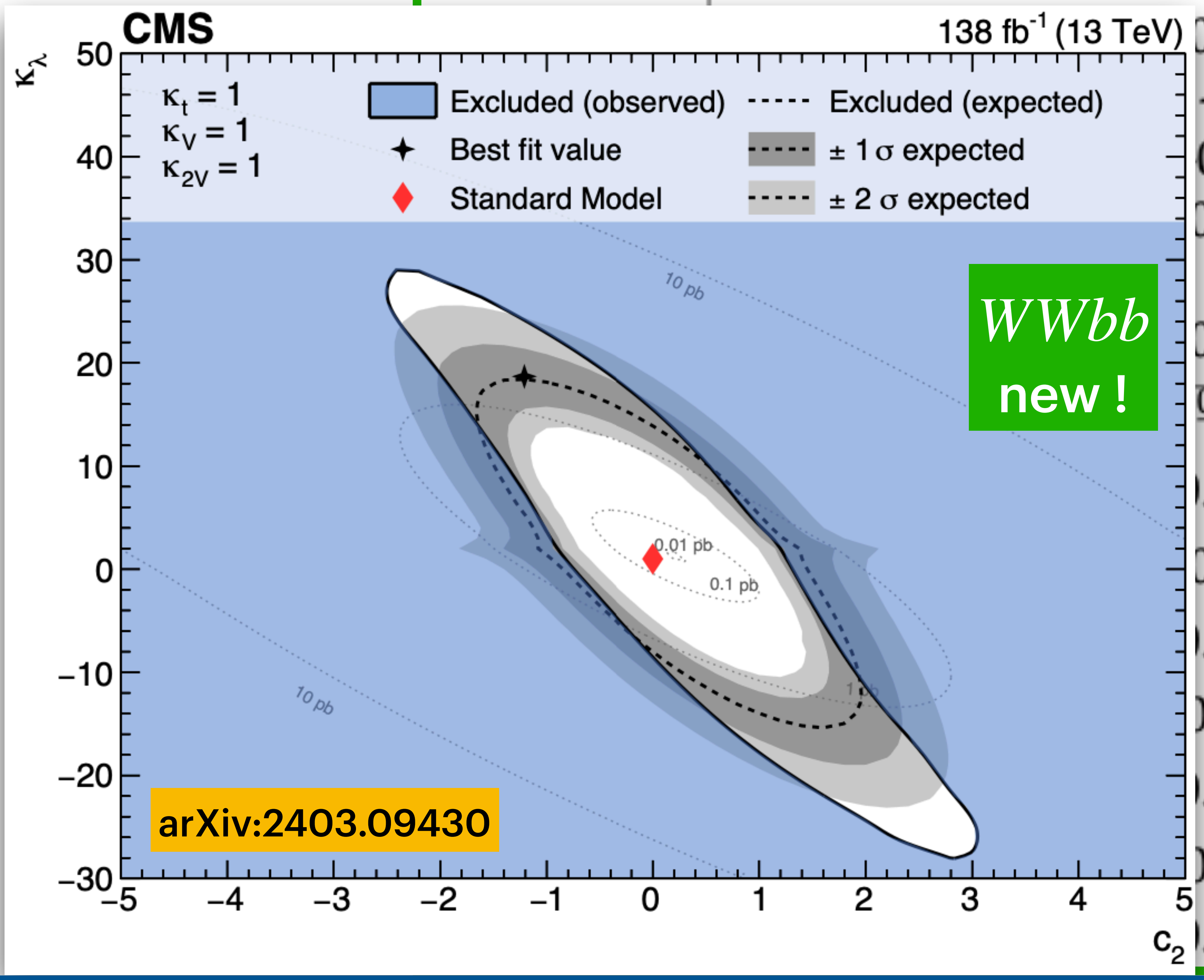
→ analyses performed by re-weighting signal samples to match each EFT benchmark
→ extract the limit for each of the benchmarks
⇒ $HH \rightarrow bbbb, WWbb, WW\gamma\gamma, Multilepton(WWWW, WW\tau\tau, \tau\tau\tau\tau)$

HEFT benchmarks

Benchmark	κ_λ	κ_t	c_2	c_g	c_{2g}
SM	1.0	1.0	0.0	0.0	0.0
1	7.5	1.0	-1.0	0.0	0.0
2	1.0	1.0	0.5	-0.8	0.6
3	1.0	1.0	-1.5	0.0	-0.8
4	-3.5	1.5	-3.0	0.0	0.0
5	1.0	1.0	0.0	0.8	-1
6	2.4	1.0	0.0	0.2	-0.2
				0.2	-0.2
				-1	1
				0.6	0.6
				0.0	0.0
				1	-1
				0.0	0.0
				0.8 3	0.0
				.75	-1
				0.0	1.0
				.75	-1.5
				.75	-0.5
				.25	1.5
				.75	-1.0
				.25	0.5



JHEP 07 (2023) 095



WWbb new !

arXiv:2403.09430

Conclusions

⇒ **Precision measurements** are key to search for deviations from the SM

⇒ CMS has several dedicated measurements for EFT effects in the Higgs sector of **SMEFT** with

→ $H \to WW$

→ $H \to \tau\tau$

and in HEFT with

→ Double-Higgs analyses

⇒ The STXS framework enables the exploration of EFT parameters **across different Higgs production modes**

→ EFT effects are parametrised in STXS bins for dedicated sensitivity assuming zero modifications in background shapes or normalisation resulting from EFT effects.

⇒ CMS and ATLAS are actively collaborating to establish a unified framework encompassing both STXS and SMEFT parametrisation within the LHC EFT Working Group, as discussed during the LHC EFT workshop in December 2022.

BACKUP - STXS bins

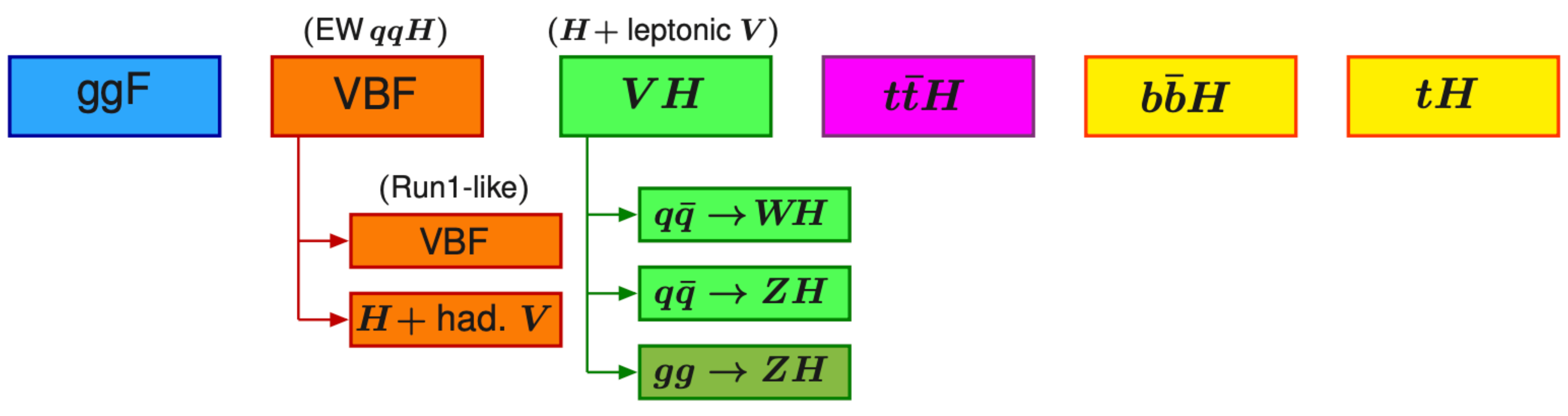
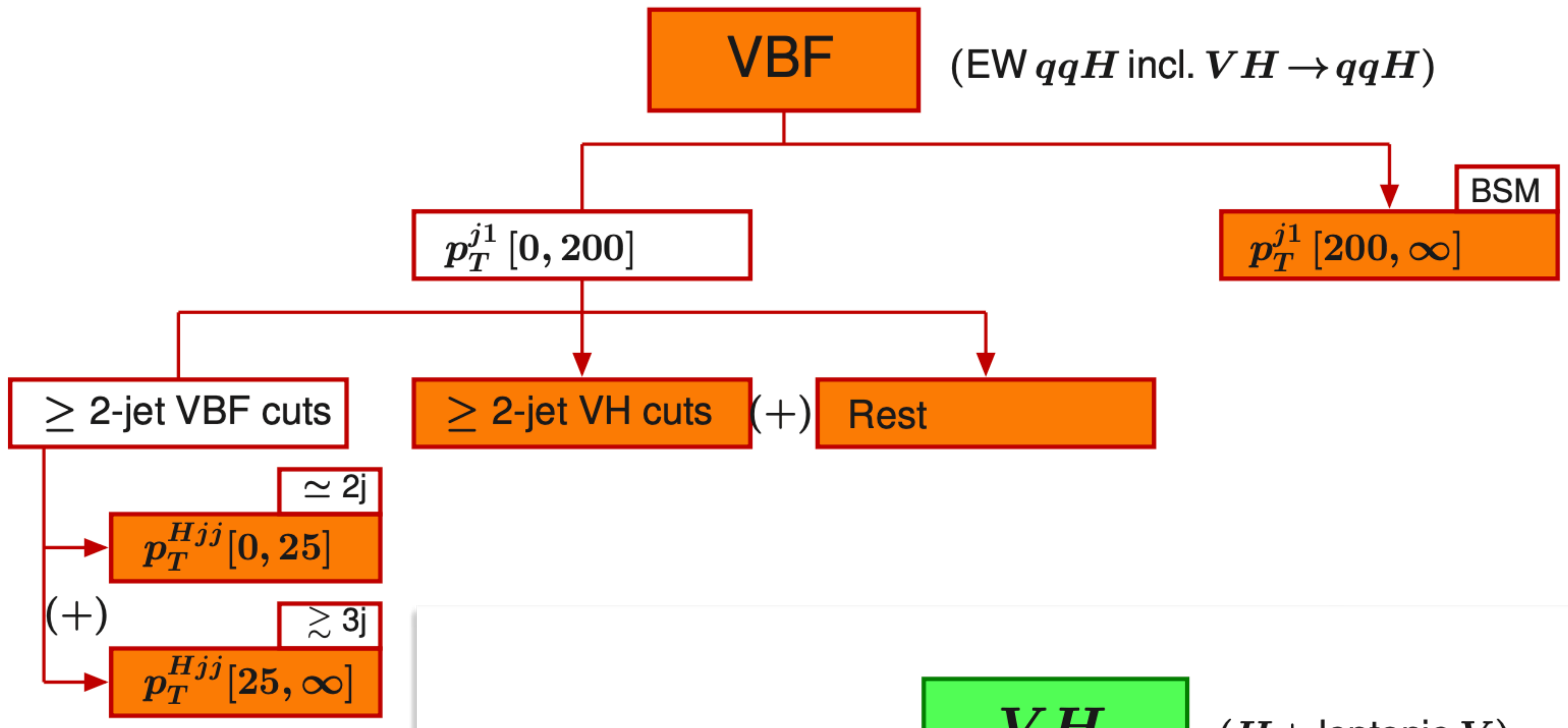


Figure 218: Stage 0 bins.



Figur

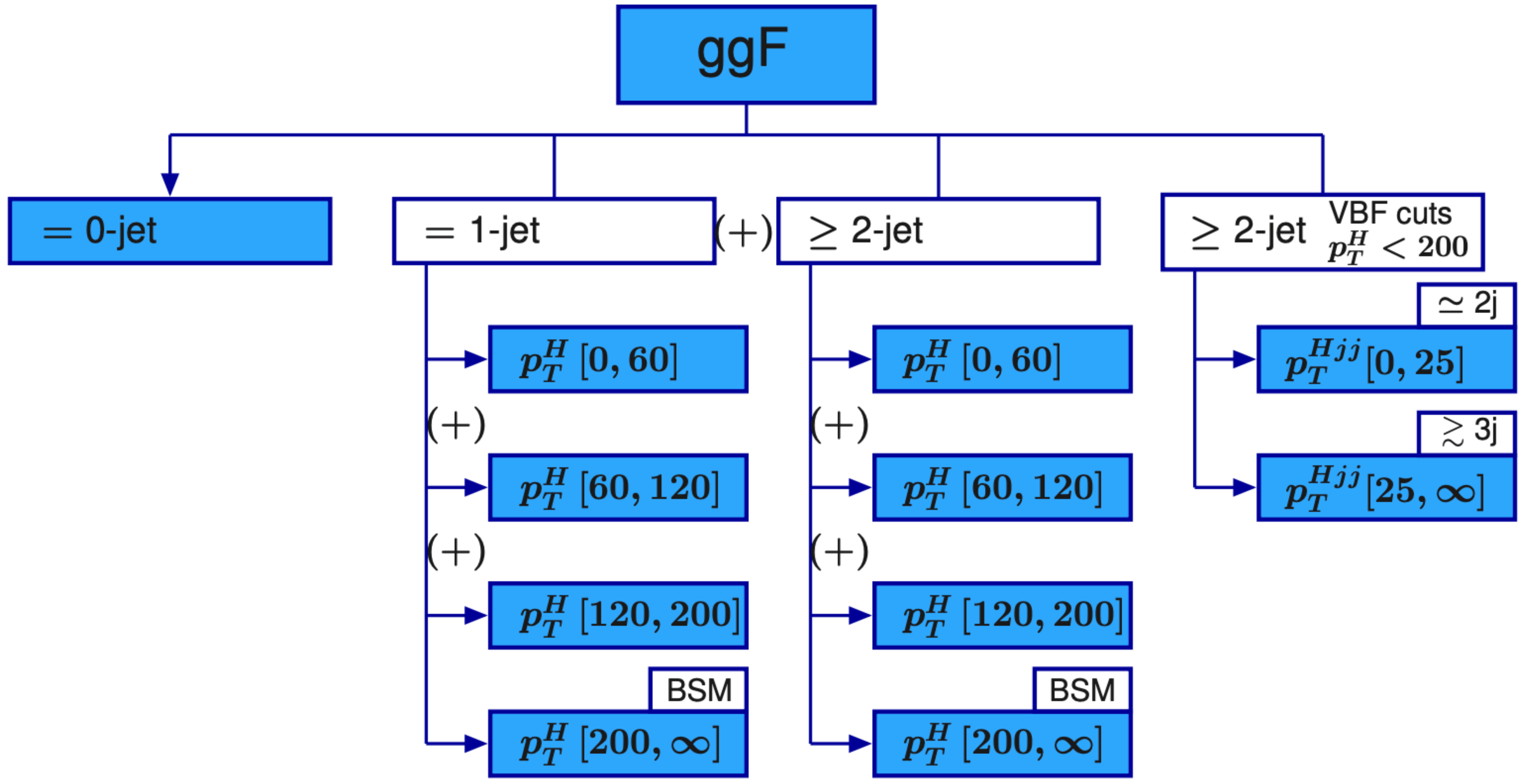


Figure 219: Stage 1 binning for gluon fusion production.

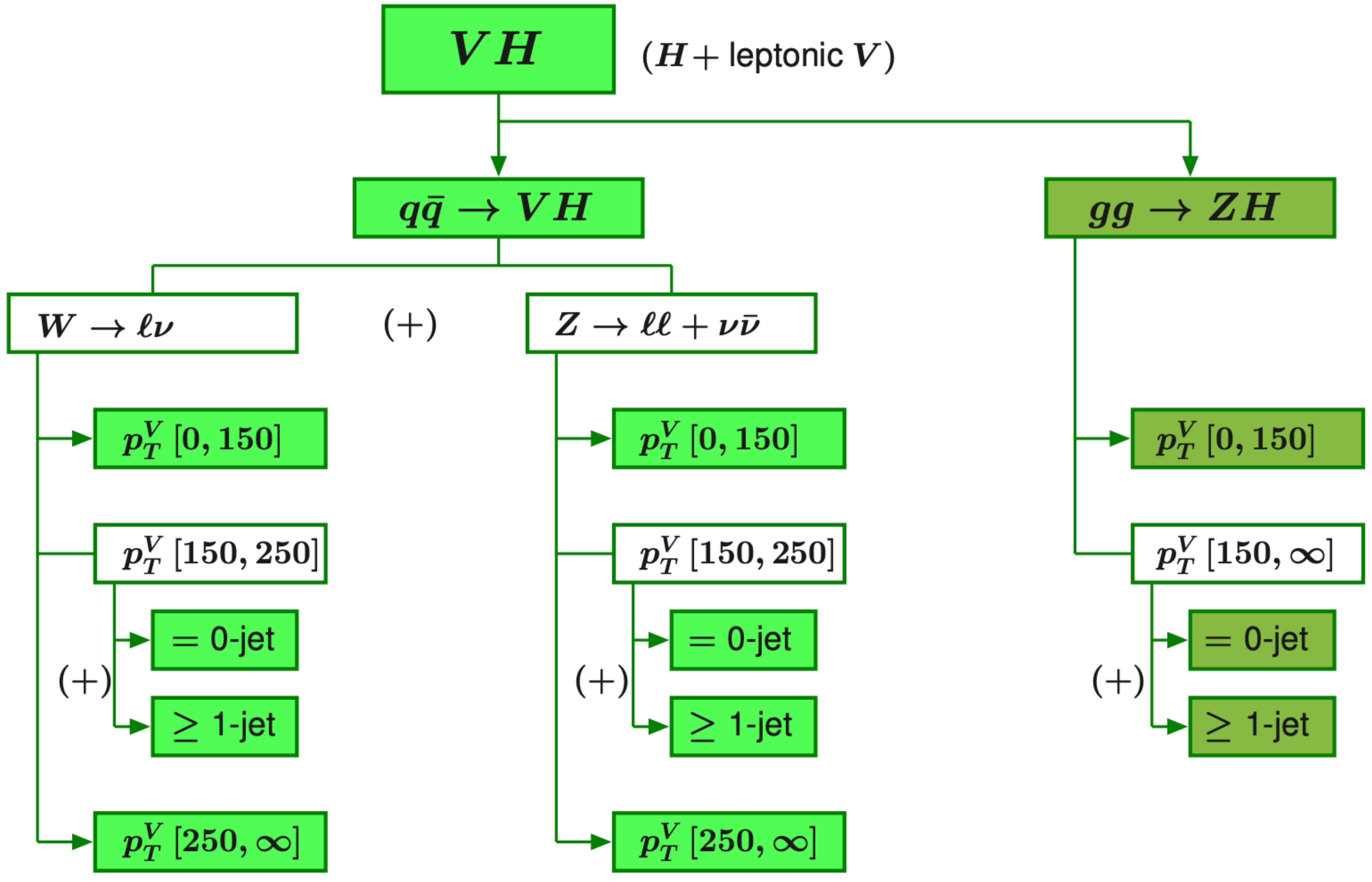


Figure 222: Stage 1 binning for associated production with vector bosons.

BACKUP - Higgs SMEFT

Warsaw Basis [link]

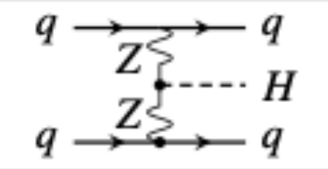
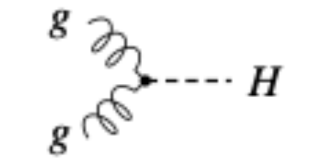
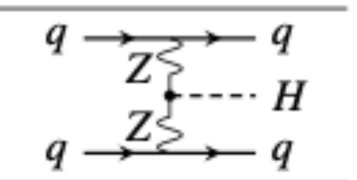
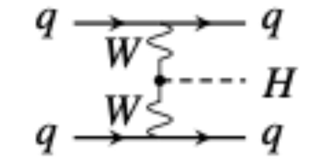
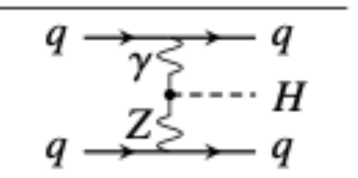
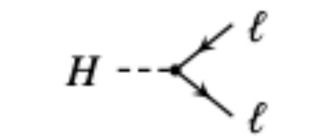
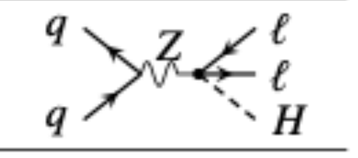
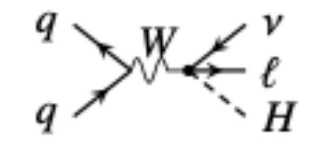
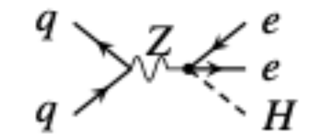
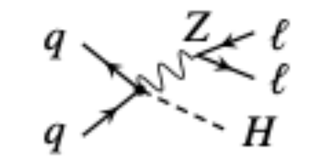
X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar l_p e_r \varphi)$
$Q_{\widetilde G}$	$f^{ABC} \widetilde G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$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

d=6 operators other than the four-fermion ones

$(\bar LL)(\bar LL)$		$(\bar RR)(\bar RR)$		$(\bar LL)(\bar RR)$	
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}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{quqd}^{(8)}$	$(\bar q_p^j T^A u_r)\varepsilon_{jk}(\bar q_s^k T^A d_t)$	$Q_{qqq}^{(1)}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar l_p^j e_r)\varepsilon_{jk}(\bar q_s^k u_t)$	$Q_{qqq}^{(3)}$	$\varepsilon^{\alpha\beta\gamma}(\tau^I\varepsilon)_{jk}(\tau^I\varepsilon)_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(3)}$	$(\bar l_p^j \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar q_s^k \sigma^{\mu\nu} u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$

four-fermion operators

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}	$(H^\dagger H)(\bar l_p e_r H)$	
$c_{Hl}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar l_p \gamma^\mu l_r)$	
$c_{Hl}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar l_p \tau^I \gamma^\mu l_r)$	
c_{He}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar e_p \gamma^\mu e_r)$	
$c_{Hq}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar q_p \gamma^\mu q_r)$	
$c_{Hq}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar q_p \tau^I \gamma^\mu q_r)$	
c_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar u_p \gamma^\mu u_r)$	
c_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar d_p \gamma^\mu d_r)$	

Definition of the most relevant EFT operators impacting the Higgs in SMEFT

$$f_{a2} = \frac{|a_2|^2\sigma_2}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + |\kappa_1|^2\sigma_{\Lambda1} + |\kappa_1^{Z\gamma}|^2\sigma_{\Lambda1}^{Z\gamma}}\ \mathrm{sgn}\left(\frac{a_2}{a_1}\right),$$

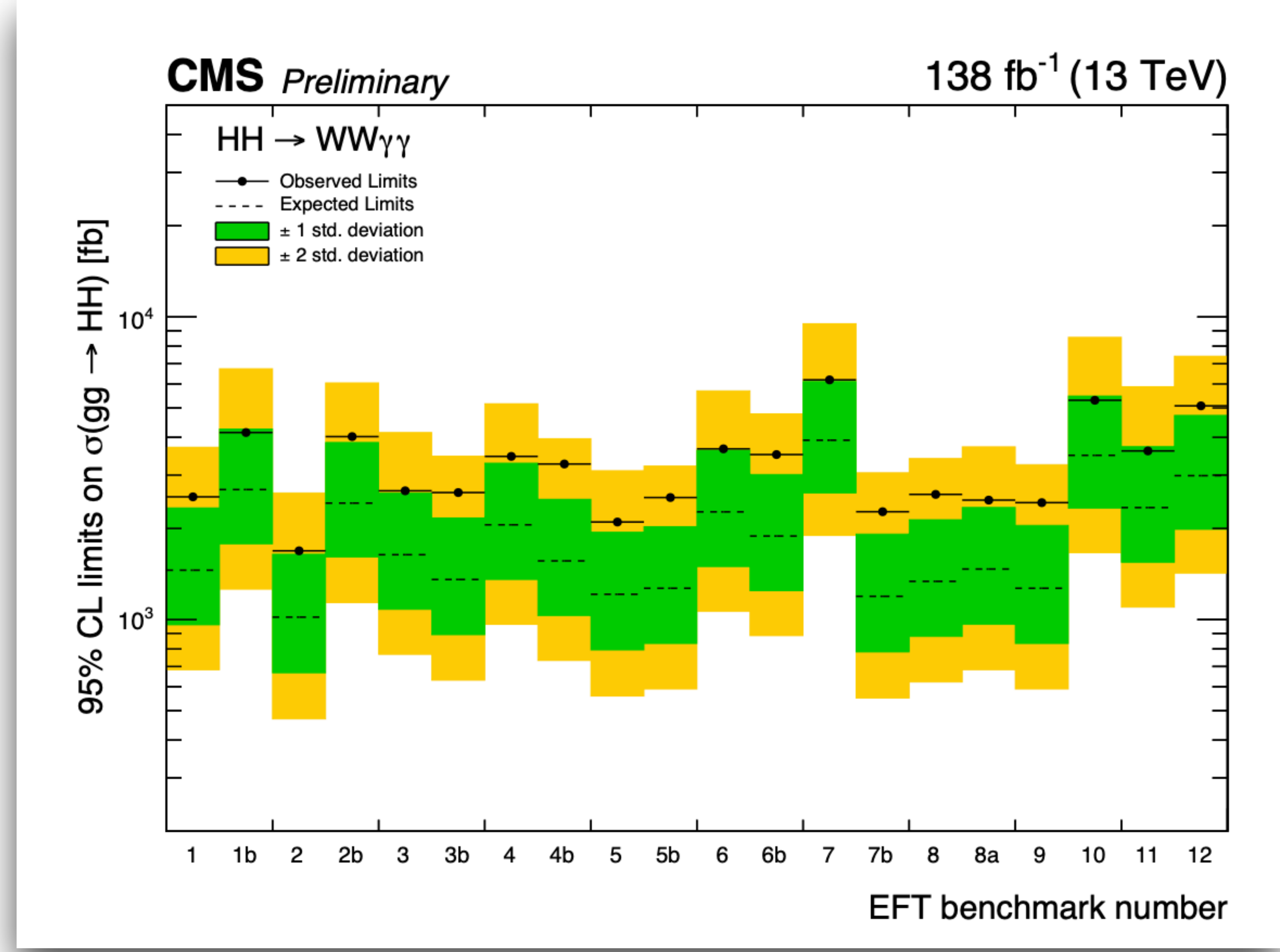
$$f_{\Lambda1} = \frac{|\kappa_1|^2\sigma_{\Lambda1}}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + |\kappa_1|^2\sigma_{\Lambda1} + |\kappa_1^{Z\gamma}|^2\sigma_{\Lambda1}^{Z\gamma}}\ \mathrm{sgn}\left(\frac{-\kappa_1}{a_1}\right),$$

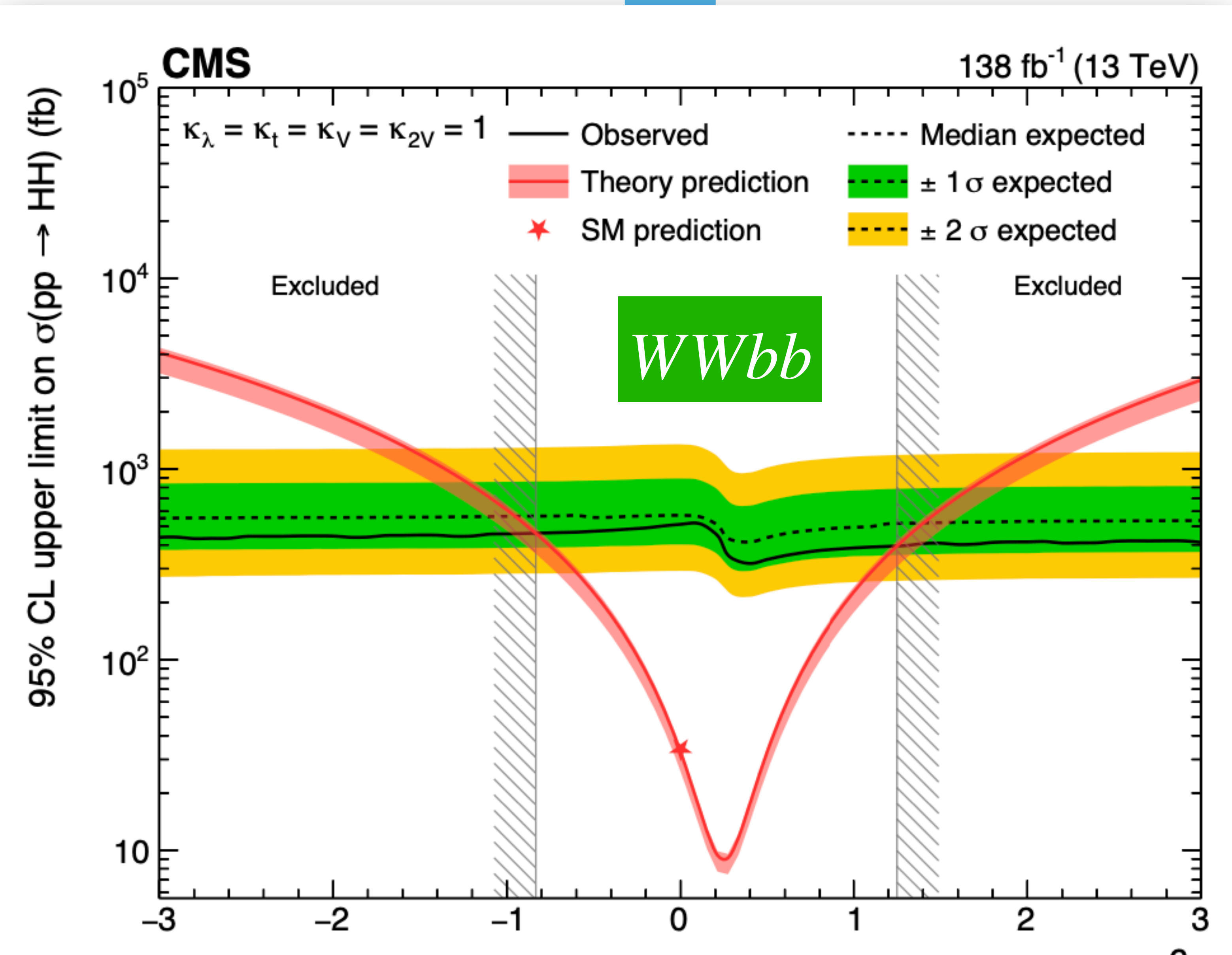
$$f_{\Lambda1}^{Z\gamma} = \frac{|\kappa_2^{Z\gamma}|^2\sigma_{\Lambda1}^{Z\gamma}}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + |\kappa_1|^2\sigma_{\Lambda1} + |\kappa_1^{Z\gamma}|^2\sigma_{\Lambda1}^{Z\gamma}}\ \mathrm{sgn}\left(\frac{-\kappa_2^{Z\gamma}}{a_1}\right),$$

cross section fractions

CMS-PAS-HIG-21-014

Benchmark	κ_λ	κ_t	c_2	c_g	c_{2g}
SM	1.0	1.0	0.0	0.0	0.0
1	7.5	1.0	-1.0	0.0	0.0
2	1.0	1.0	0.5	-0.8	0.6
3	1.0	1.0	-1.5	0.0	-0.8
4	-3.5	1.5	-3.0	0.0	0.0
5	1.0	1.0	0.0	0.8	-1
6	2.4	1.0	0.0	0.2	-0.2
7	5.0	1.0	0.0	0.2	-0.2
8	15.0	1.0	0.0	-1	1
9	1.0	1.0	1.0	-0.6	0.6
10	10.0	1.5	-1.0	0.0	0.0
11	2.4	1.0	0.0	1	-1
12	15.0	1.0	1.0	0.0	0.0
8a	1.0	1.0	0.5	$\frac{0.8}{3}$	0.0
1b	3.94	0.94	$\frac{-1}{3}$	0.75	-1
2b	6.84	0.61	$\frac{1}{3}$	0.0	1.0
3b	2.21	1.05	$\frac{-1}{3}$	0.75	-1.5
4b	2.79	0.61	$\frac{1}{3}$	-0.75	-0.5
5b	3.95	1.17	$\frac{-1}{3}$	0.25	1.5
6b	5.68	0.83	$\frac{1}{3}$	-0.75	-1.0
7b	-0.10	0.94	1.0	0.25	0.5





arXiv:2403.09430