Higgs / Top / EWK and combined EFT results at CMS

LHCPhysics
Belgrade, 22 - 26 May 2023

Davide Valsecchi
for the CMS collaboration

ETH zürich

CMS
Compact Muon Solenoid

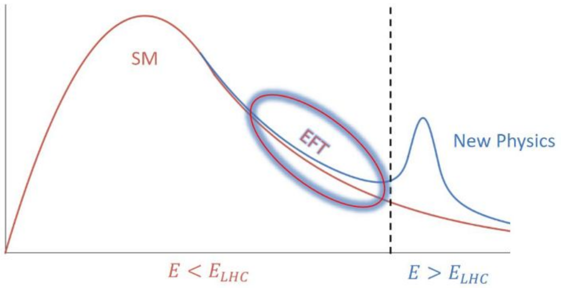
Introduction to EFT

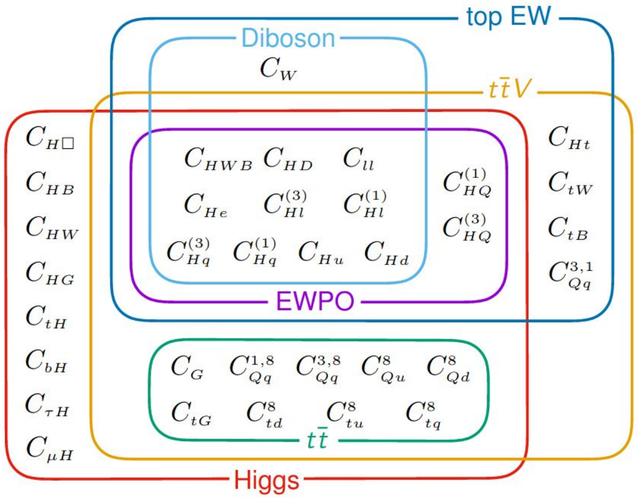
- SMEFT: Probe indirect signals of new physics in an **agnostic** & **systematic way**
- SMEFT operators have a **global effect**
  - → need a **global measurement strategy** from experiments
  - → different channels have sensitivity on subsets of operators (sensitivity study from LHC-EFT-WG)
  - → flat directions (operators with similar effect) can be ruled out with **combination**

Violates B,L

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \cancel{\frac{1}{\Lambda}\mathcal{L}_5} + \boxed{\frac{1}{\Lambda^2}\mathcal{L}_6} + \frac{1}{\Lambda^3}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \dots$$

leading deviation from SM





- **Common set of recommendations** fundamental (LHC EFT WG Report):
  - → Choice of basis and input parameters
  - → Best-practice for simulation and reweighting
  - → Choice of parametrization for observables
  - → Choice of analysis phase-spaces to avoid double-counting

EFT analysis strategies in CMS

EFT analyses can follow an indirect or direct approach

Indirect approach

- ○ **Reinterpretation** of fiducial (differential) cross-sections measurements (e.g STXS in the Higgs)
  - More re-interpretable, easier to preserve
- ○ Access to **more operators** but with limited sensitivity (not optimized for EFT)
  - constraint power from combination
  - flat directions can be disentangle with PCA → challenge for theory usage
- ○ **Acceptance effects** difficult to model for some channels

$L(data|\sigma_i)$

$L(data|\sigma_i(c_j))$

Direct approach

- ○ BSM effect **fully simulated** to detector-level. Analyses optimized for EFT parameters sensitivity
- ○ More difficult to preserve (MVAs, full detector reco)
- ○ May be **optimal for a set of operators**, but can be computationally expensive
- ○ Combination possible but more difficult (overlaps)
- ○ Optimal observables:
  - Based on Matrix Element Method (MELA)
  - Based on parameterized classifiers optimized with ML → learns the structure of the likelihood ratio

$L(data|c_j)$

EFT in Top Physics

Analysis approaches:

- unfolded cross-sections
- direct measurements using optimal observables or ML discriminators

Parametrizations:

- Warsaw basis: *dim6top* or SMEFT@NLO

In this talk:

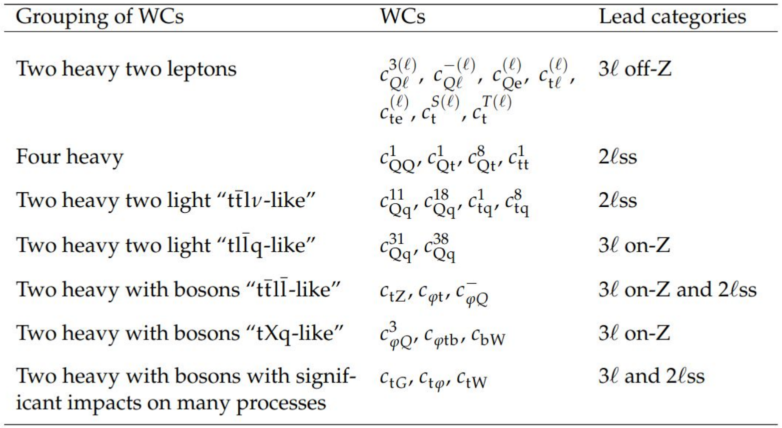
- Recent tt+X analysis
- tt+H/Z boosted analysis

tt+X multi-lepton analysis

CMS-PAS-TOP-22-006

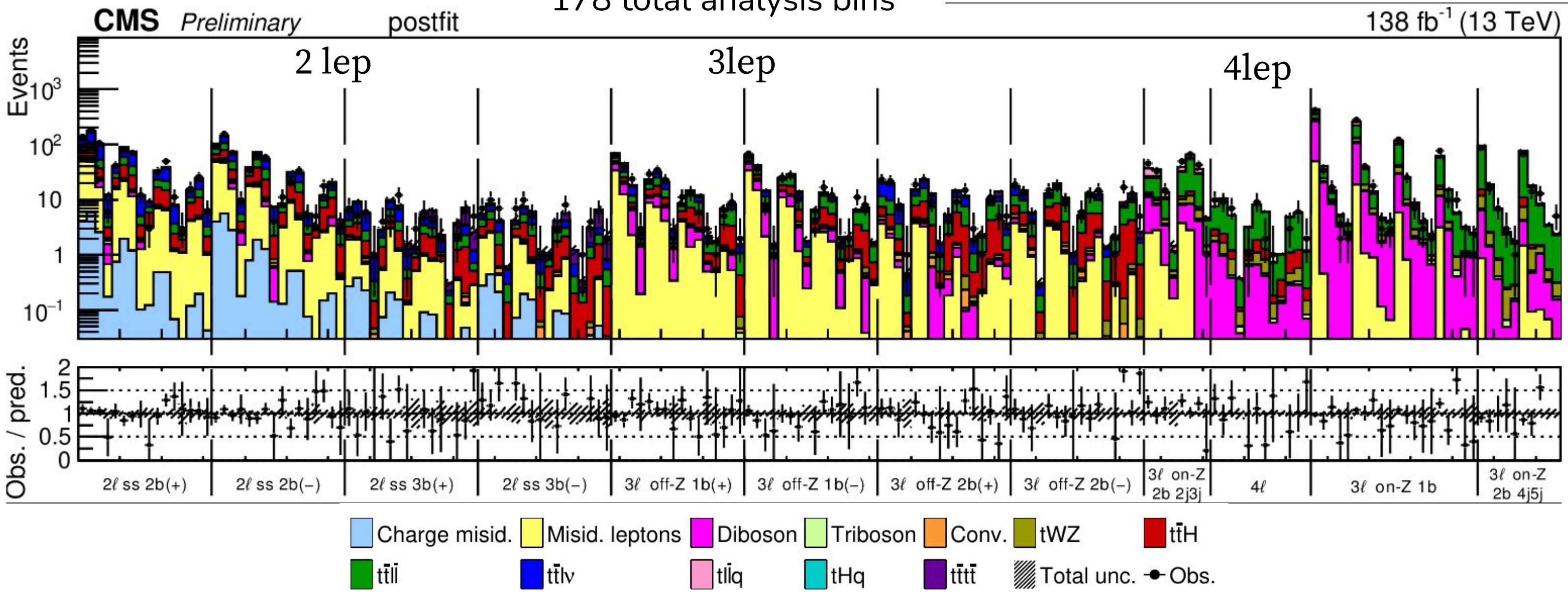
- **Most comprehensive** CMS EFT analysis about top-related operators
  - → Targeting ttH, ttZ, ttW, tHq, tZq, tttt processes
- Broad multilepton + jet multiplicity categorization
- Fit $p_T(\ell j)_0$ or $p_T(Z)$ variable: sum of the momenta of the pair of jets/leptons with the largest p_T → high **sensitivity to tails** for most operators
- 26 WC fitted together → analyze **different processes all together**

Most sensitive category for each operator



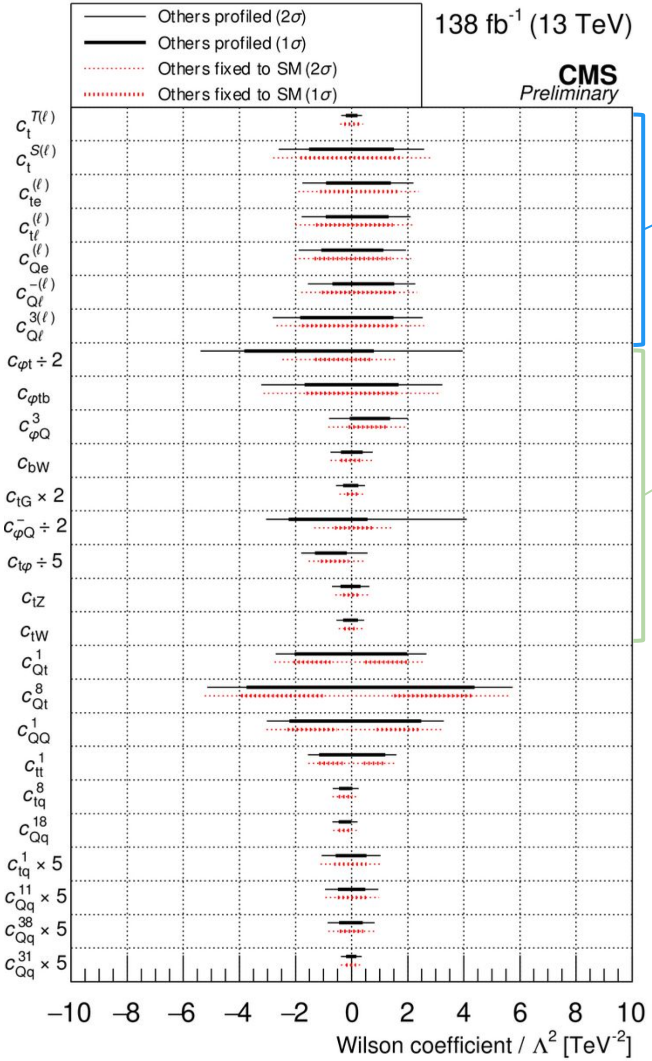
Grouping of WCs	WCs	Lead categories
Two heavy two leptons	$c_{Q\ell}^{3(\ell)}$, $c_{Q\ell}^{-(\ell)}$, $c_{Qe}^{(\ell)}$, $c_{t\ell}^{(\ell)}$, $c_{te}^{(\ell)}$, $c_{t}^{S(\ell)}$, $c_{t}^{T(\ell)}$	3ℓ off-Z
Four heavy	c_{QQ}^{1}, c_{Qt}^{1}, c_{Qt}^{8}, c_{tt}^{1}	2ℓss
Two heavy two light "$t\bar{t}l\nu$-like"	c_{Qq}^{11}, c_{Qq}^{18}, c_{tq}^{1}, c_{tq}^{8}	2ℓss
Two heavy two light "$tl\bar{l}q$-like"	c_{Qq}^{31}, c_{Qq}^{38}	3ℓ on-Z
Two heavy with bosons "$t\bar{t}l\bar{l}$-like"	c_{tZ}, $c_{\varphi t}$, $c_{\varphi Q}^{-}$	3ℓ on-Z and 2ℓss
Two heavy with bosons "tXq-like"	$c_{\varphi Q}^{3}$, $c_{\varphi tb}$, c_{bW}	3ℓ on-Z
Two heavy with bosons with significant impacts on many processes	c_{tG}, $c_{t\varphi}$, c_{tW}	3ℓ and 2ℓss

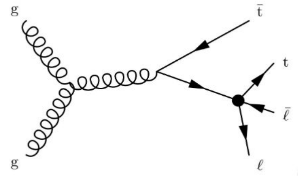
178 total analysis bins



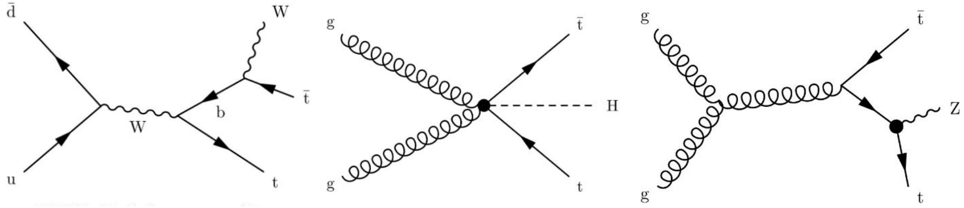
tt+X: operators constraints

CMS-PAS-TOP-22-006

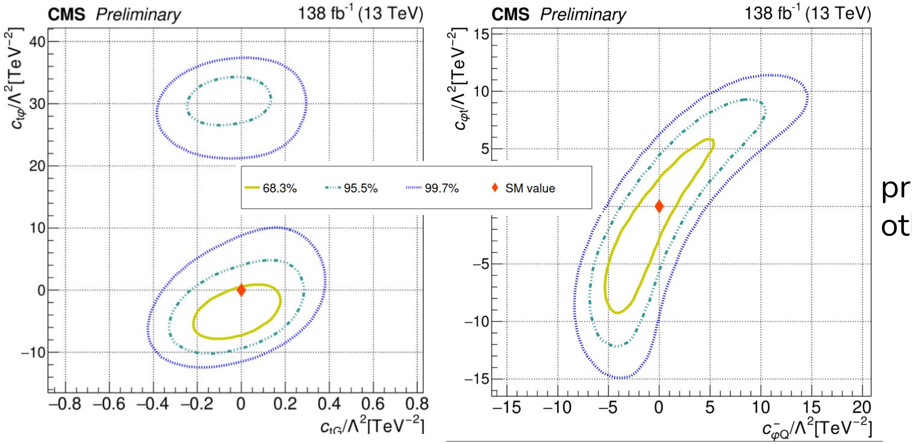




7 out of 8 top-lepton CP-even operators constrained



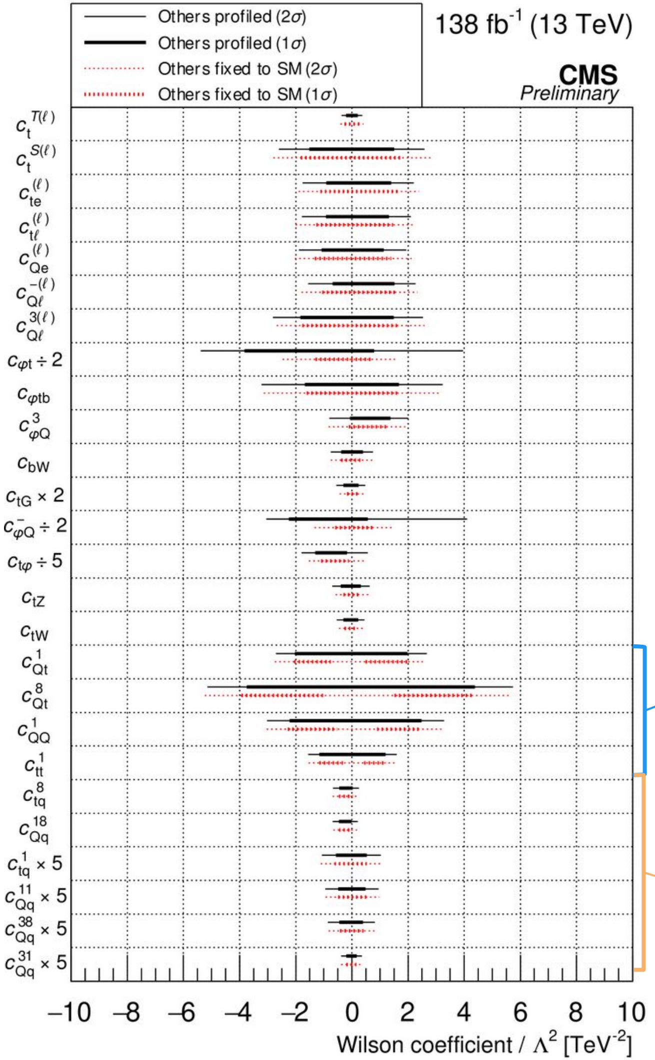
9 CP-even top-boson operators
Targets simultaneously ttH, ttW, ttZ, tttt

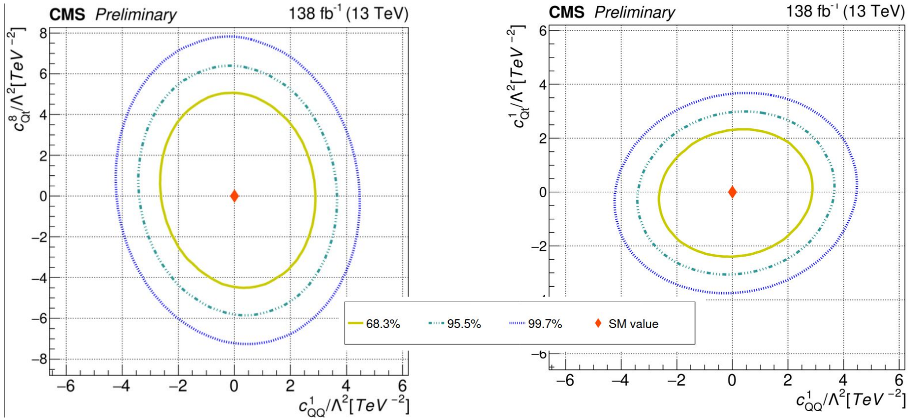


profiling other WCs

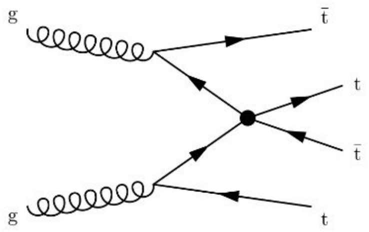
tt+X: operators constraints

CMS-PAS-TOP-22-006

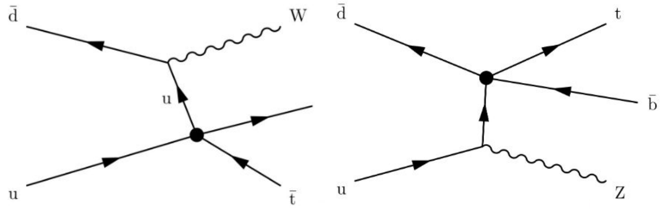




profiling other WCs



4 four-heavy quarks operators constrained from tttt and ttbb production



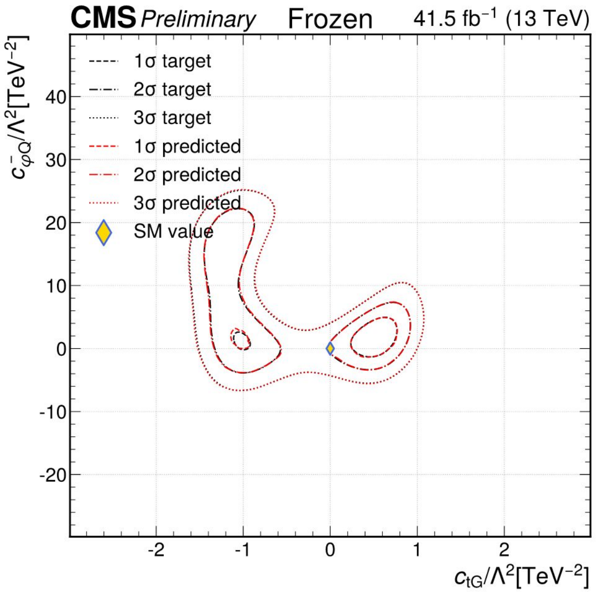
6 two-heavy-two-light operators constrained with qq-induced processes (ttW, tZq)

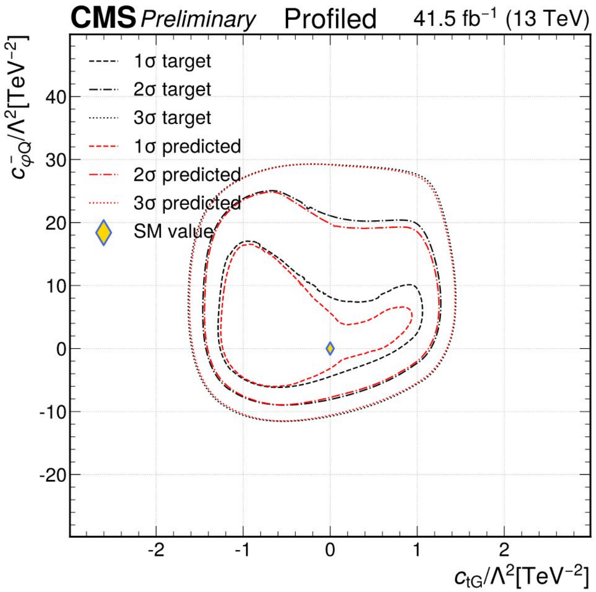
tt+X: toward likelihood publication

Very challenging fit given the **26 POIs** and **178** analysis bins: published 1D/2D of WCs

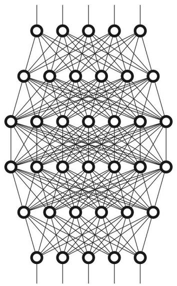
Towards **publication of the full profiled likelihood over the WC**:

- Proof-of-concept developed on **previous iteration of tt+X analysis** (doi:JHEP03(2021)095)
- Trained a **neural network** to save the likelihood function around the SM point in **16D (WCs POIs)**
  - Very fast high dimensional evaluation
- It would allows **theorists to use the full profiled likelihood** instead of 1D/2D scans





16 WC

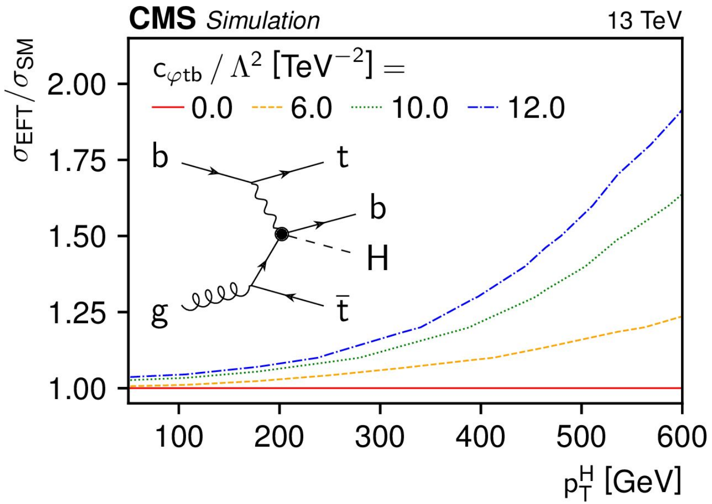


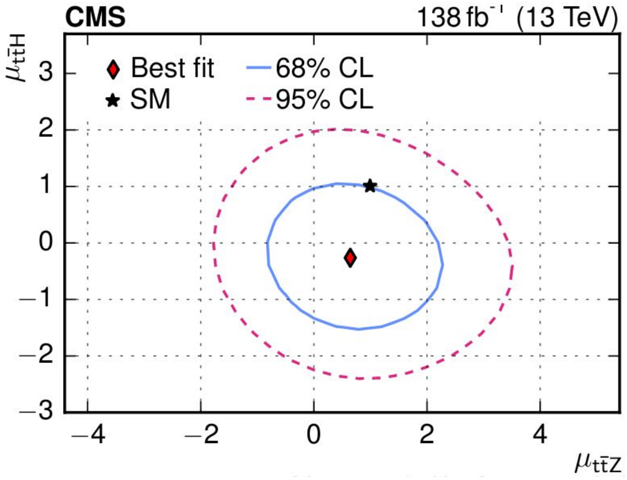
nuisances-profiled likelihood function

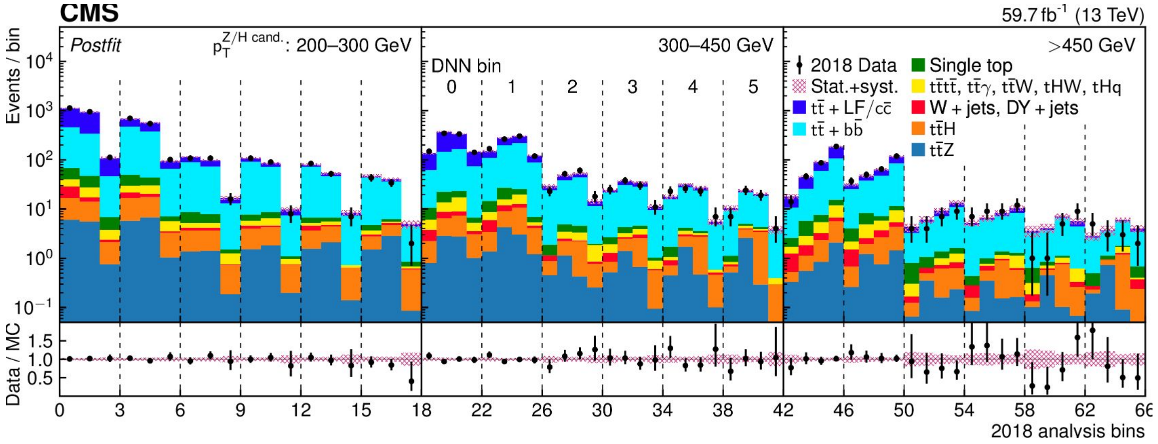
tt+H/Z in the boosted channel

Submitted to PRD arXiv2208.12837

- Single lepton + 1 tagged AK8 jet (H→ bb discriminator)
- Targeting EFT effects in **tt + boosted H/Z** and ttbb
- **3D fit**: AK8 jet mass, p_T Z/H candidate, and DNN discriminating tt+bb from ttH/Z
- Measuring **8 top+boson** operators (all of them but CtG)
- First analysis to explore EFT effect in the "**background**": C_{Wb} WC in tt+bb





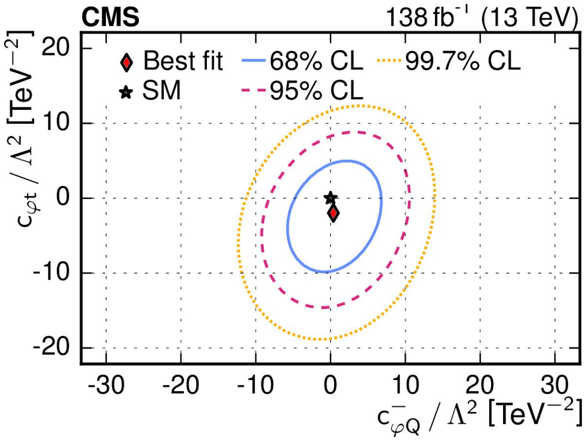


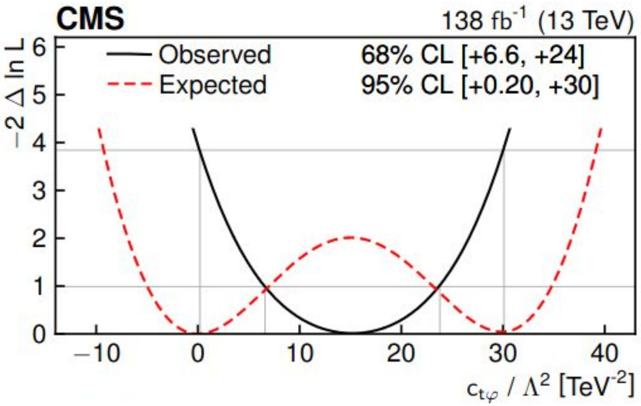
tt+bb postfit yield observed higher than SM → using most update Powheg 4FS prediction

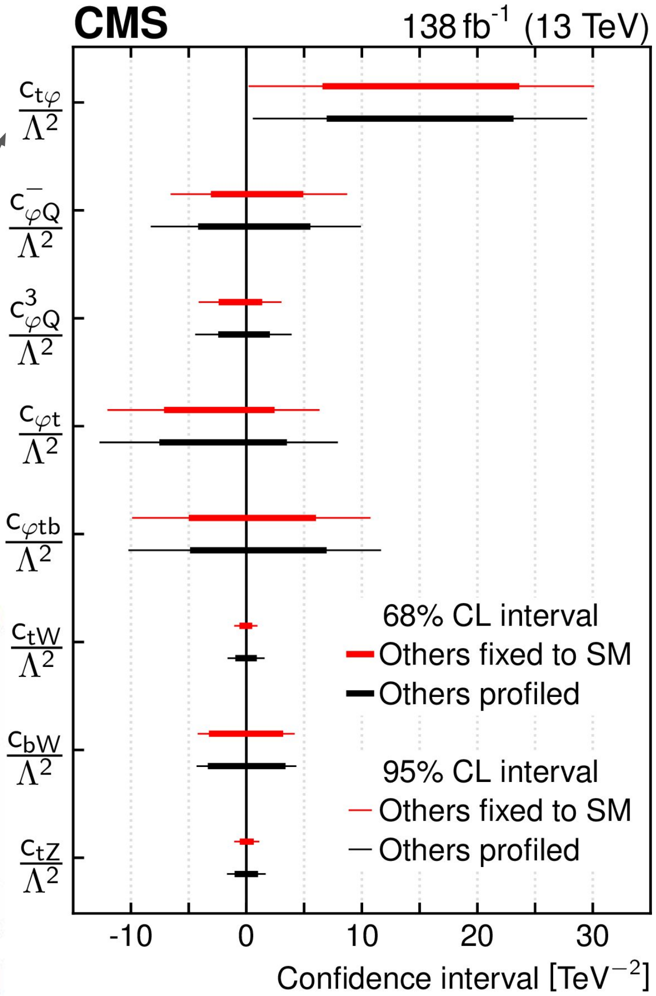
ttH/Z boosted: results

Submitted to PRD arXiv2208.12837

- Reported upper limits on ttZ/H differential XS and **1D/2D CI of 8 WC.**
- Tension in $C_{t\varphi}$ correlated to upper postfit deviation of tt+bb yield
- Scan the three pairs of WCs that exhibit the largest postfit correlations $(c_{\varphi t}, c^{-}_{\varphi Q})$ $(c^{3}_{\varphi Q}, c^{-}_{\varphi Q})$ (c_{tW}, c_{tZ})







EFT in Higgs Physics

Analysis approaches:

- Matrix element observables (MELA)
- Re-interpretation of inclusive and differential XS
- STXS framework

Parametrizations:

- Anomalous couplings
- Higgs Effective Lagrangian (HEL) model
- more recently Warsaw basis in SMEFT

In this talk:

- Recent H->ττ AC analysis
- STXS pre-legacy Run2 combination

Higgs anomalous couplings

Direct analysis following the **anomalous couplings (AC)** parametrization
→ target ggH and VBS Higgs productions

Limits on AC parameters can be rotated to Warsaw basis WC limits.

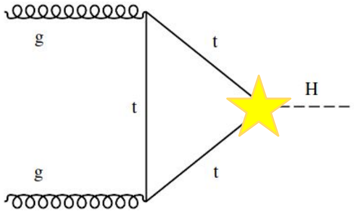
AC approach/SMEFT approach
1 Anomalous coupling:
$\tilde{\kappa}_f$: ~~CP~~

AC approach	**SMEFT approach**
$a_i^{ZZ}=a_i^{WW}$	SU(2) X U(1)
4 anomalous couplings:	$a_i^{ZZ} \neq a_i^{WW}$
a_2 (CP)	3 anomalous couplings:
a_3 ~~(CP)~~	a_2 (CP)
$a_{\Lambda 1}$ (CP)	a_3 ~~(CP)~~
$a_{\Lambda 1}^{Z\gamma}$ (CP)	$a_{\Lambda 1}$ (CP)

$$A(\mathrm{Hff}) = -\frac{m_{\mathrm{f}}}{v}\bar{\psi}_{\mathrm{f}}\left(\kappa_{\mathrm{f}} + \mathrm{i}\tilde{\kappa}_{\mathrm{f}}\gamma_5\right)\psi_{\mathrm{f}}\,,$$

CP-even

CP-odd

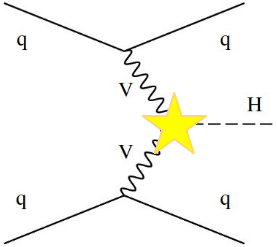


$$A(\mathrm{HVV}) = \frac{1}{v}\left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{VV}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2} + \frac{\kappa_3^{\mathrm{VV}}(q_{\mathrm{V1}}+q_{\mathrm{V2}})^2}{\left(\Lambda_Q^{\mathrm{VV}}\right)^2}\right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + \frac{1}{v} a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + \frac{1}{v} a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}\,,$$

SM

CP-even

CP-odd



$$f_{CP}^{\mathrm{Hff}} = \frac{|\tilde{\kappa}_{\mathrm{f}}|^2}{|\kappa_{\mathrm{f}}|^2 + |\tilde{\kappa}_{\mathrm{f}}|^2}\,\mathrm{sign}\left(\frac{\tilde{\kappa}_{\mathrm{f}}}{\kappa_{\mathrm{f}}}\right)$$

Observables:
XS fractions

$$f_{ai} = \frac{|a_i|^2\sigma_i}{\sum_{j=1,2,3\ldots}|a_j|^2\sigma_j}\,\mathrm{sign}\left(\frac{a_i}{a_1}\right)$$

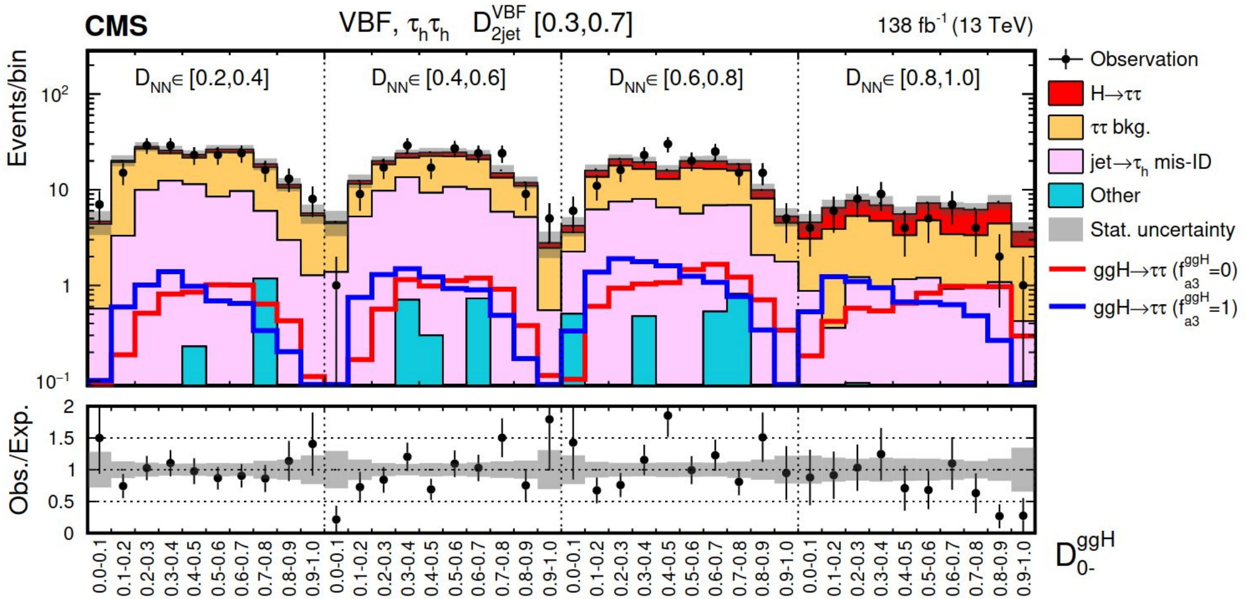
Most recent AC analysis: Hττ

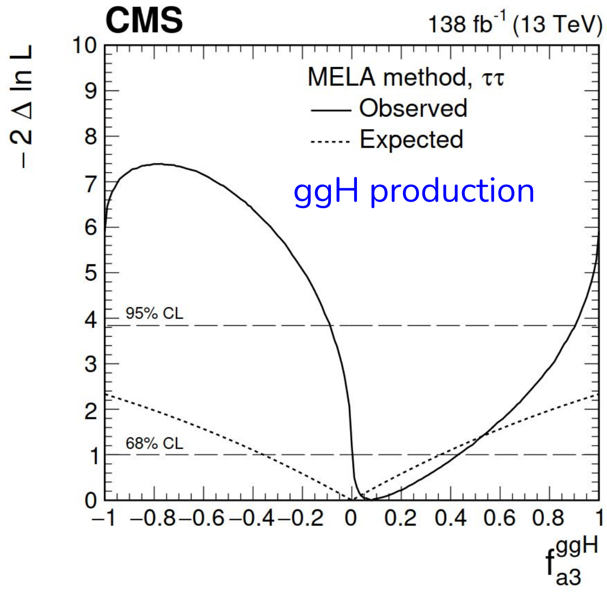
Submitted to PRD arXiv2205.05120

- DNN for **signal vs background**, combined with
- **Matrix Element Method** (MEM) to isolate BSM effects
  - MELA tool using JHUGEN generator
  - Encode maximal information in a limited number of theory-driven observables
- Most stringents CP violations limits in ggH

$$\mathcal{D}_{\mathrm{BSM}} = \frac{\mathcal{P}_{\mathrm{SM}}(\vec{\Omega})}{\mathcal{P}_{\mathrm{SM}}(\vec{\Omega}) + \mathcal{P}_{\mathrm{BSM}}(\vec{\Omega})},$$

Coupling	Discriminant
a_3^{gg}	$\mathcal{D}_{0-}^{ggH}$
a_3	$\mathcal{D}_{0-}$
a_2	$\mathcal{D}_{0h+}$
κ_1	$\mathcal{D}_{\Lambda 1}$
$\kappa_2^{Z\gamma}$	$\mathcal{D}_{\Lambda 1}^{Z\gamma}$





Higgs combination

CMS-PAS-HIG-19-005

Latest public result: partial Run2 combination **in the STXS framework**

- Inputs: $H \rightarrow \gamma\gamma$, $4l$, $l\nu l\nu$, bb, $\tau\tau$, $\mu\mu$ and $ttH \rightarrow$ multilepton $H \rightarrow \tau\tau$, WW, ZZ

Higgs Effective Lagrangian (**HEL**) model: not trivial to compare with Warsaw basis results

Measured cG , cA, cu, cd, cl, cHW, cWW, cB, other WV fixed to 0.

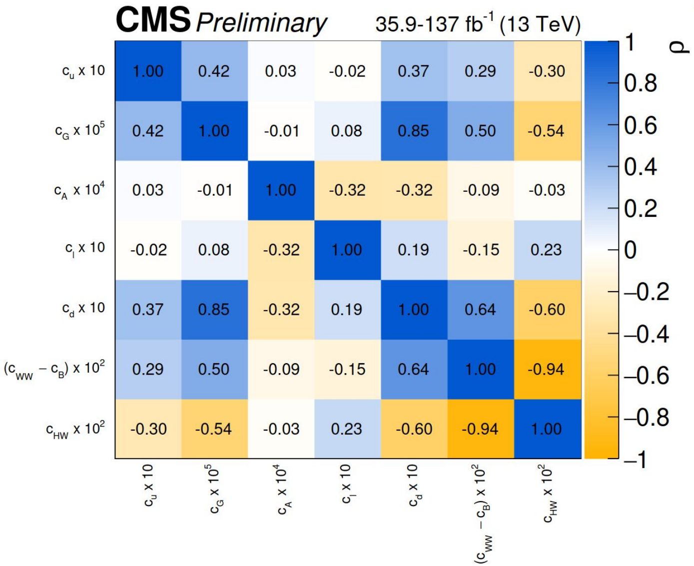
- Results consistent with SM

Acceptance effects **not taken** into account

A lot of **improvements** and new developments ongoing and not yet public

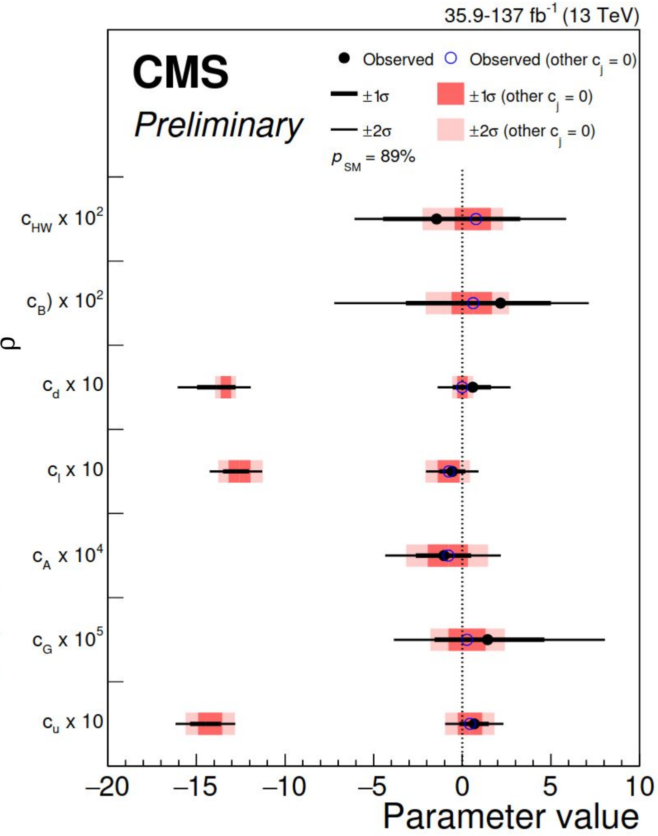
- All channels included
- Updated parametrization
- Acceptance corrections
- Improved tools for re-interpretations

More news soon!



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

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



EFT in EWK Physics

Analysis approaches:

- differential XS interpretation
- dedicated analyses optimized for BSM

Parametrizations:

- aQGCs, aTGCs
- dim-6 Warsaw basis
- dim-8 Eboli and other bases

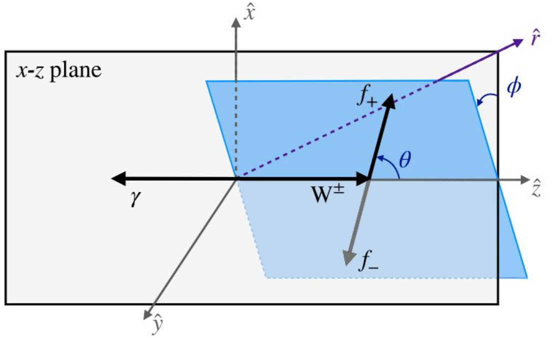
In this talk:

- W+ɣ differentials
- Wɣ + jets VBS

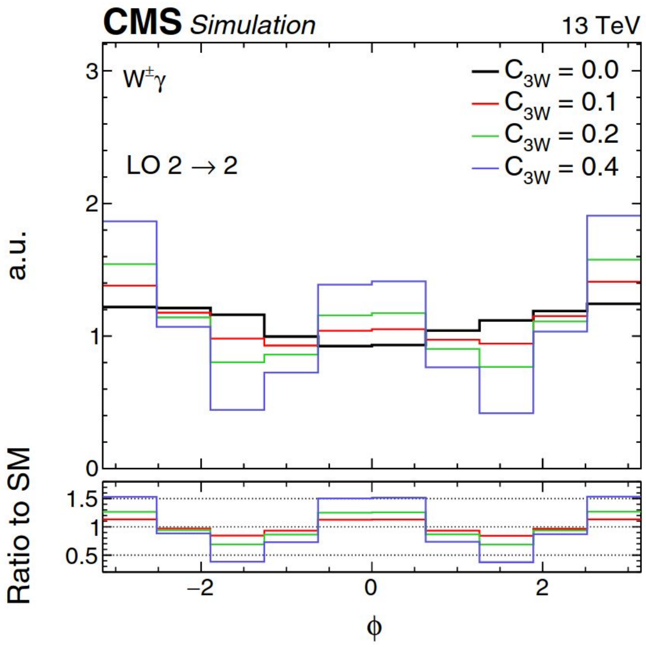
W+ɣ differential

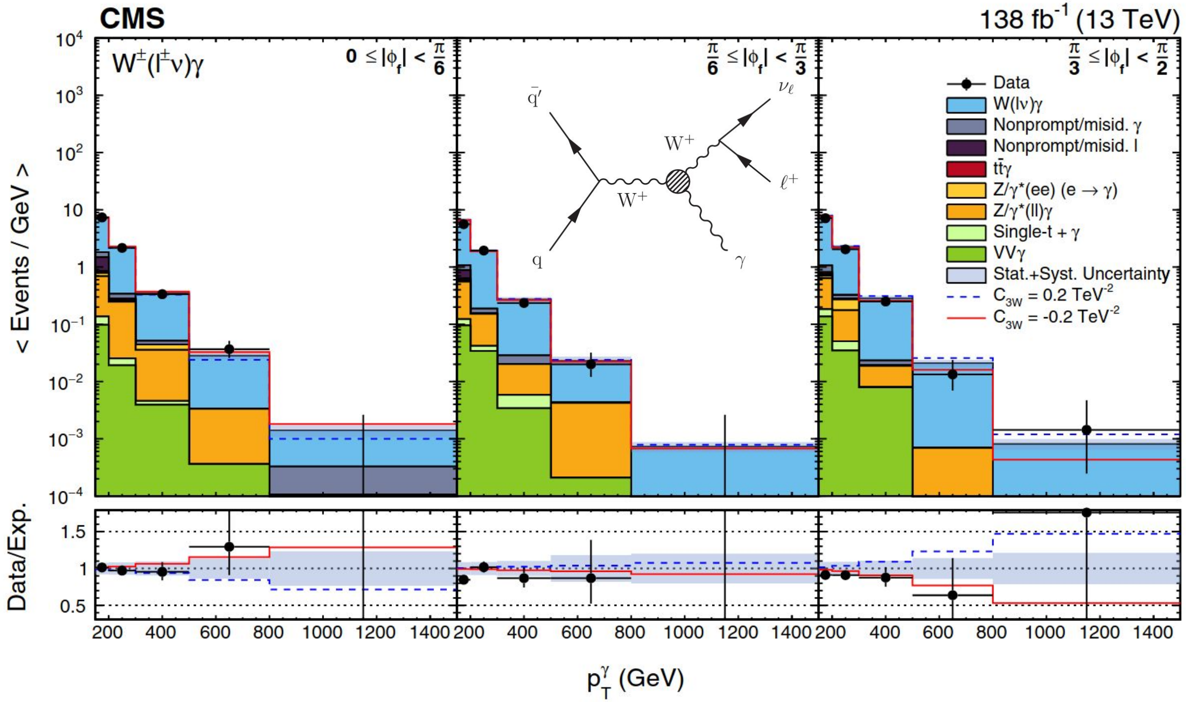
10.1103/PhysRevD.105.052003

- ○ Differential XS measurement and limits on O_{3W} in dim-6 EFT
- ○ *ff* → $W_T V_T$ have different helicities for SM and BSM:
  - **interference effects cancels** out for inclusive observables like photon p_T
- ○ **“Interference resurrection”**: measure decay angles of the final state fermions in Wɣ CM frame



$$\mathcal{O}_{3W} = \epsilon^{ijk} W_\mu^{i\nu} W_\nu^{j\rho} W_\rho^{k\mu}$$

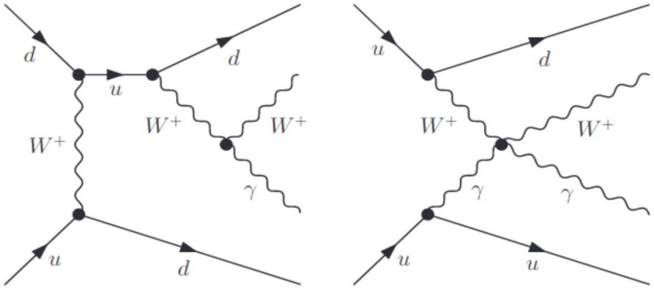




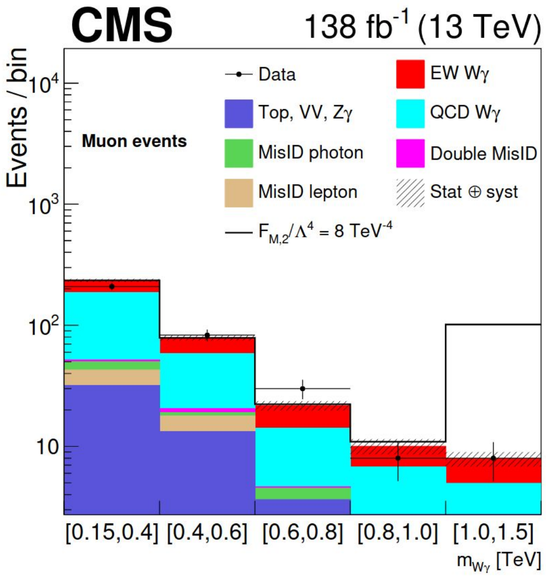
Wɣ + jets: aQGC measurement

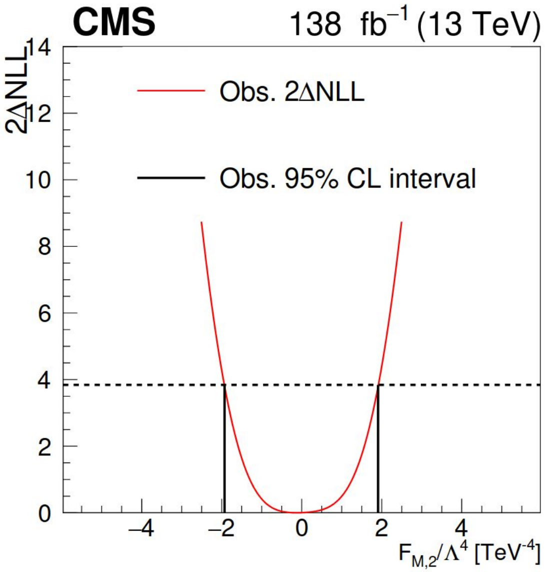
Submitted to PRD arXiv:2212.12592

- VBS is ideal to measure **anomalous quartic gauge couplings** (aQGC)
  - **dim-8** EFT operators
- Interference between EW Wɣ and QCD irreducible background fully taken into account
- **Most stringent limits to date** on the aQGC parameters $f_{M,2-5}/\Lambda^4$ and $f_{T,6-7}/\Lambda^4$



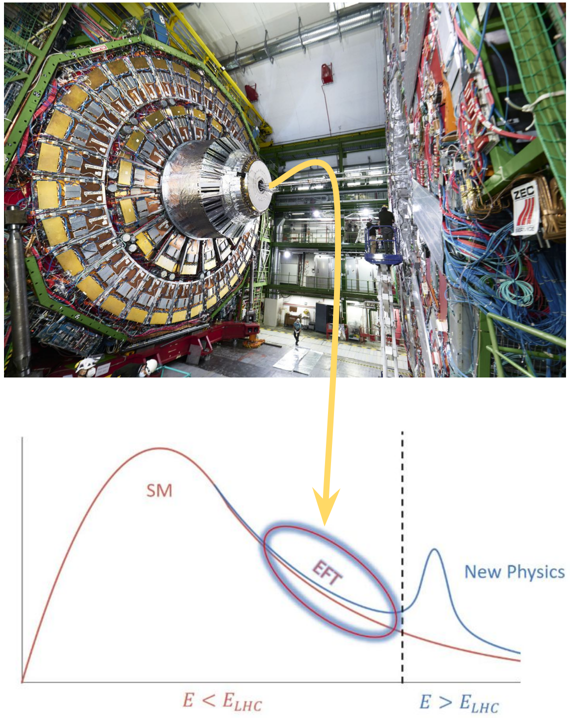
Expected limit	Observed limit	U_{bound}
$-5.1 < f_{M,0}/\Lambda^4 < 5.1$	$-5.6 < f_{M,0}/\Lambda^4 < 5.5$	1.7
$-7.1 < f_{M,1}/\Lambda^4 < 7.4$	$-7.8 < f_{M,1}/\Lambda^4 < 8.1$	2.1
$-1.8 < f_{M,2}/\Lambda^4 < 1.8$	$-1.9 < f_{M,2}/\Lambda^4 < 1.9$	2.0
$-2.5 < f_{M,3}/\Lambda^4 < 2.5$	$-2.7 < f_{M,3}/\Lambda^4 < 2.7$	2.7
$-3.3 < f_{M,4}/\Lambda^4 < 3.3$	$-3.7 < f_{M,4}/\Lambda^4 < 3.6$	2.3
$-3.4 < f_{M,5}/\Lambda^4 < 3.6$	$-3.9 < f_{M,5}/\Lambda^4 < 3.9$	2.7
$-13 < f_{M,7}/\Lambda^4 < 13$	$-14 < f_{M7}/\Lambda^4 < 14$	2.2
$-0.43 < f_{T,0}/\Lambda^4 < 0.51$	$-0.47 < f_{T,0}/\Lambda^4 < 0.51$	1.9
$-0.27 < f_{T,1}/\Lambda^4 < 0.31$	$-0.31 < f_{T,1}/\Lambda^4 < 0.34$	2.5
$-0.72 < f_{T,2}/\Lambda^4 < 0.92$	$-0.85 < f_{T,2}/\Lambda^4 < 1.0$	2.3
$-0.29 < f_{T,5}/\Lambda^4 < 0.31$	$-0.31 < f_{T,5}/\Lambda^4 < 0.33$	2.6
$-0.23 < f_{T,6}/\Lambda^4 < 0.25$	$-0.25 < f_{T,6}/\Lambda^4 < 0.27$	2.9
$-0.60 < f_{T,7}/\Lambda^4 < 0.68$	$-0.67 < f_{T,7}/\Lambda^4 < 0.73$	3.1





Conclusions

- EFT analyses are **experimentally challenging**
  - **Global effects** on many processes and observables
  - Both effects in the **tails** and in the **bulk** (angular observables)
- **CMS** is exploring many different paths in EFT:
  - **Direct** and **indirect** measurements
  - Broad **combinations of channels** and **dedicated** measurements
  - **Optimised observables** bases on MEM or machine learning for best sensitivity
- **Combination** (within CMS and with ATLAS) needed to extract best limits and reduce flat directions

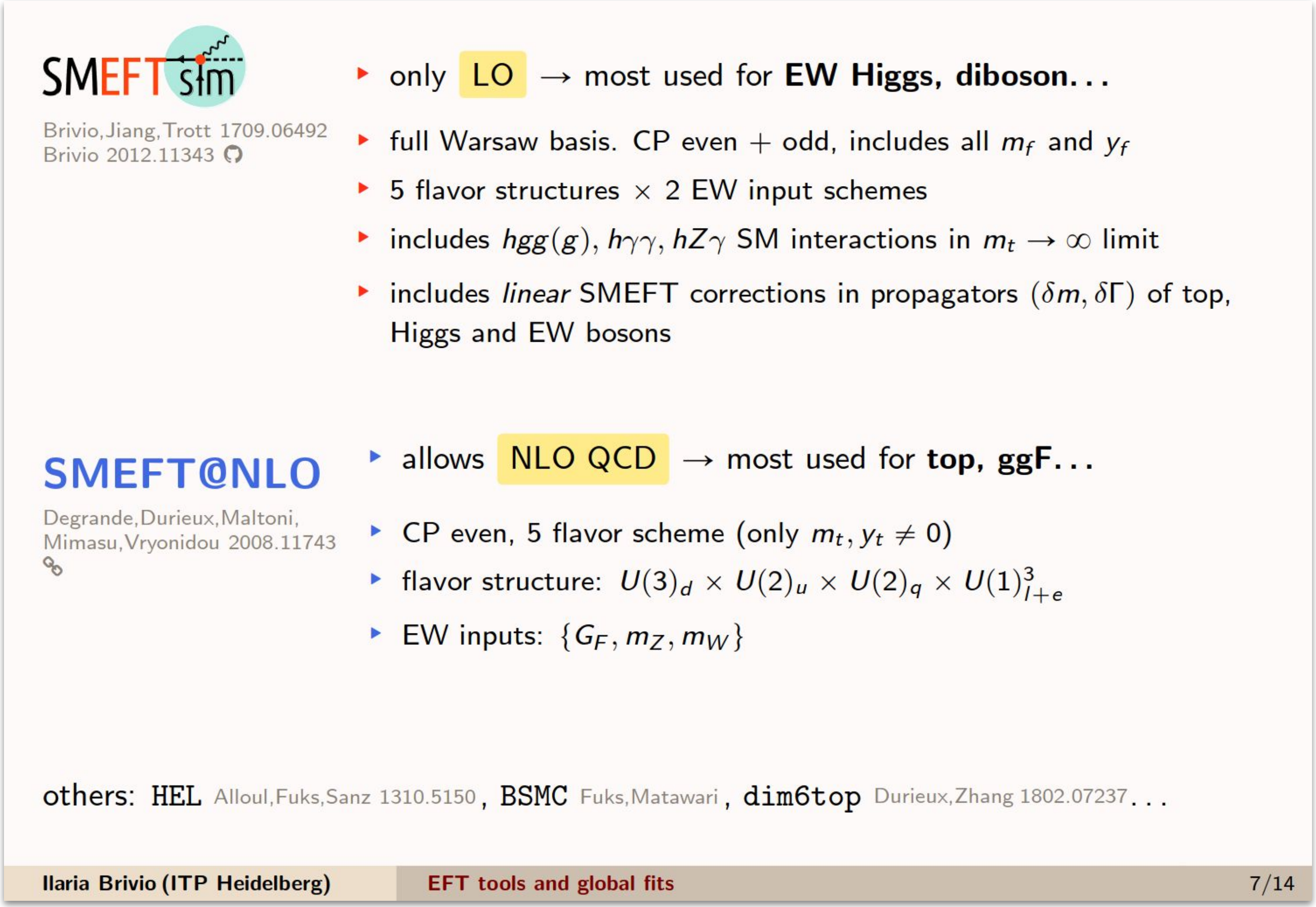


Questions?

Backup

SMEFT tools

Slides from I. Brivio



SMEFTsim

Brivio, Jiang, Trott 1709.06492
Brivio 2012.11343

- only LO → most used for **EW Higgs, diboson. . .**
- full Warsaw basis. CP even + odd, includes all m_f and y_f
- 5 flavor structures × 2 EW input schemes
- includes $hgg(g)$, $h\gamma\gamma$, $hZ\gamma$ SM interactions in $m_t \to \infty$ limit
- includes *linear* SMEFT corrections in propagators $(\delta m, \delta\Gamma)$ of top, Higgs and EW bosons

SMEFT@NLO

Degrande, Durieux, Maltoni, Mimasu, Vryonidou 2008.11743

- allows NLO QCD → most used for **top, ggF. . .**
- CP even, 5 flavor scheme (only $m_t, y_t \neq 0$)
- flavor structure: $U(3)_d \times U(2)_u \times U(2)_q \times U(1)^3_{l+e}$
- EW inputs: $\{G_F, m_Z, m_W\}$

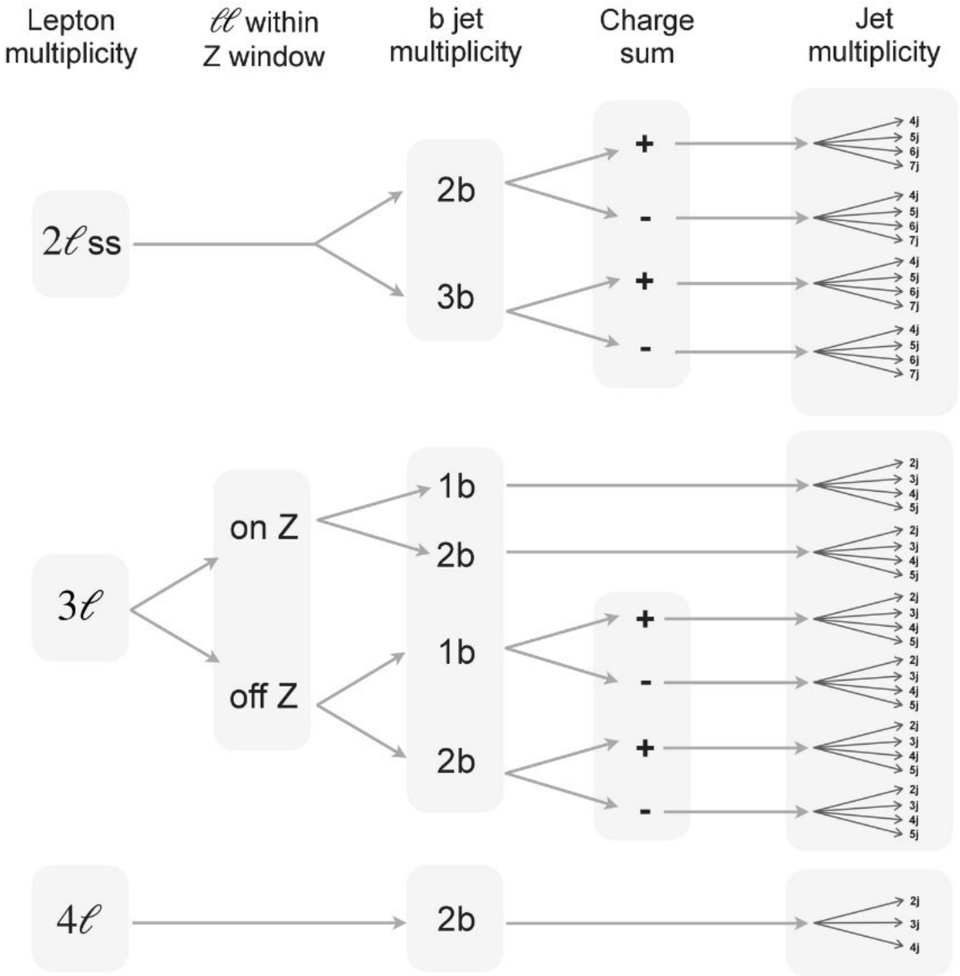
others: `HEL` Alloul, Fuks, Sanz 1310.5150 , `BSMC` Fuks, Matawari , `dim6top` Durieux, Zhang 1802.07237 . . .

Ilaria Brivio (ITP Heidelberg) EFT tools and global fits 7/14

Public Higgs anomalous coupling analyses

CMS Analysis	Channel	Measurement	Combined with	Reference
HIG-19-009	On-shell $H\to ZZ$	HVV, Hgg, Htt	[Htt] $H\to\gamma\gamma$ [HIG-19-013]	PRD 104 (2021) 052004
HIG-21-013	Off-shell $H\to ZZ$	HVV	On-shell $H\to ZZ$	NP (2022) 01682
HIG-20-007	$H\to\tau\tau$	HVV, Hgg, Htt	On-shell $H\to ZZ$ and $H\to\gamma\gamma$	arXiV: 2205.05120 (Accepted by PRD)
HIG-21-006	ttH and tH multilepton	Htt	On-shell $H\to ZZ$ and $H\to\gamma\gamma$	arXiv: 2208.02686 (Accepted by JHEP)
HIG-20-006	$H\to\tau\tau$	$H\tau\tau$	-	JHEP 06 (2022) 012

tt+X categorization



Lepton multiplicity

$\ell\ell$ within Z window

b jet multiplicity

Charge sum

Jet multiplicity

2ℓss

2b

3b

\+

\-

\+

\-

4j
5j
6j
7j

4j
5j
6j
7j

4j
5j
6j
7j

4j
5j
6j
7j

3ℓ

on Z

off Z

1b

2b

1b

2b

\+

\-

\+

\-

2j
3j
4j
5j

2j
3j
4j
5j

2j
3j
4j
5j

2j
3j
4j
5j

2j
3j
4j
5j

2j
3j
4j
5j

4ℓ

2b

2j
3j
4j

AC to SMEFT

$$
\begin{aligned}
A(\mathrm{HV_1V_2}) = \frac{1}{v}\left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{VV}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2} + \frac{\kappa_3^{\mathrm{VV}} (q_{\mathrm{V1}} + q_{\mathrm{V2}})^2}{\left(\Lambda_{\mathrm{Q}}^{\mathrm{VV}}\right)^2}\right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* \\
+ \frac{1}{v} a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + \frac{1}{v} a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu},
\end{aligned}
$$

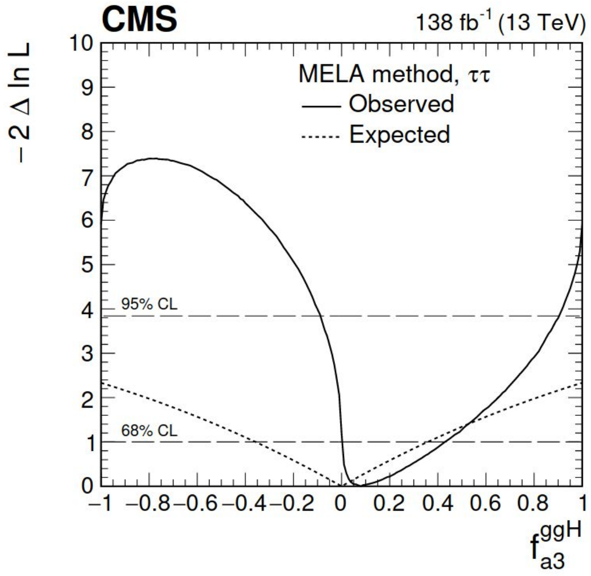
$$\updownarrow$$

$$
\begin{aligned}
\mathcal{L}_{\mathrm{hvv}} \quad = \quad & \frac{h}{v}\left[(1+\delta c_w)\frac{g^2 v^2}{2} W_\mu^+ W_\mu^- + (1+\delta c_z)\frac{(g^2+g'^2)v^2}{4} Z_\mu Z_\mu \right. \\
& + c_{ww}\frac{g^2}{2} W_{\mu\nu}^+ W_{\mu\nu}^- + \tilde{c}_{ww}\frac{g^2}{2} W_{\mu\nu}^+ \tilde{W}_{\mu\nu}^- + c_{w\Box} g^2 \left(W_\mu^- \partial_\nu W_{\mu\nu}^+ + \mathrm{h.c.}\right) \\
& + c_{gg}\frac{g_s^2}{4} G_{\mu\nu}^a G_{\mu\nu}^a + c_{\gamma\gamma}\frac{e^2}{4} A_{\mu\nu} A_{\mu\nu} + c_{z\gamma}\frac{e\sqrt{g^2+g'^2}}{2} Z_{\mu\nu} A_{\mu\nu} + c_{zz}\frac{g^2+g'^2}{4} Z_{\mu\nu} Z_{\mu\nu} \\
& + c_{z\Box} g^2 Z_\mu \partial_\nu Z_{\mu\nu} + c_{\gamma\Box} g g' Z_\mu \partial_\nu A_{\mu\nu} \\
& \left. + \tilde{c}_{gg}\frac{g_s^2}{4} G_{\mu\nu}^a \tilde{G}_{\mu\nu}^a + \tilde{c}_{\gamma\gamma}\frac{e^2}{4} A_{\mu\nu} \tilde{A}_{\mu\nu} + \tilde{c}_{z\gamma}\frac{e\sqrt{g^2+g'^2}}{2} Z_{\mu\nu} \tilde{A}_{\mu\nu} + \tilde{c}_{zz}\frac{g^2+g'^2}{4} Z_{\mu\nu} \tilde{Z}_{\mu\nu} \right],
\end{aligned}
$$

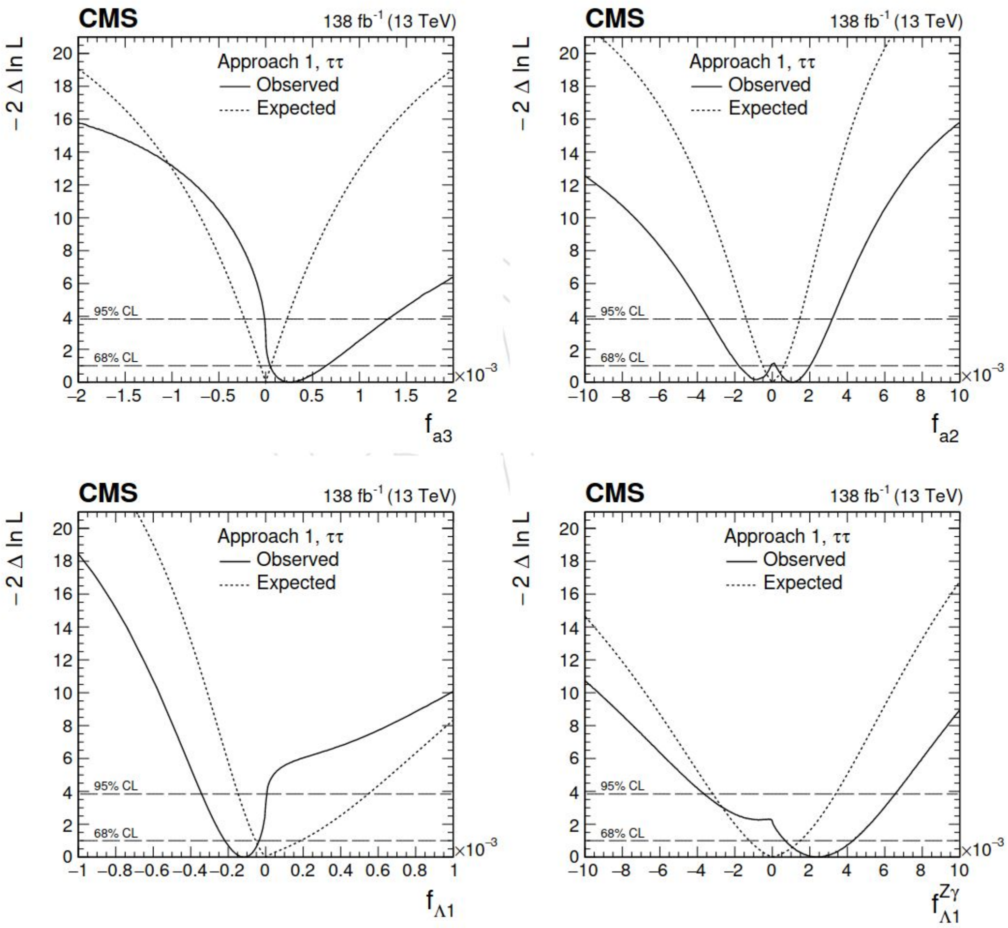
Hττ anomalous coupling: full results

Submitted to PRD arXiv2205.05120

ggH production

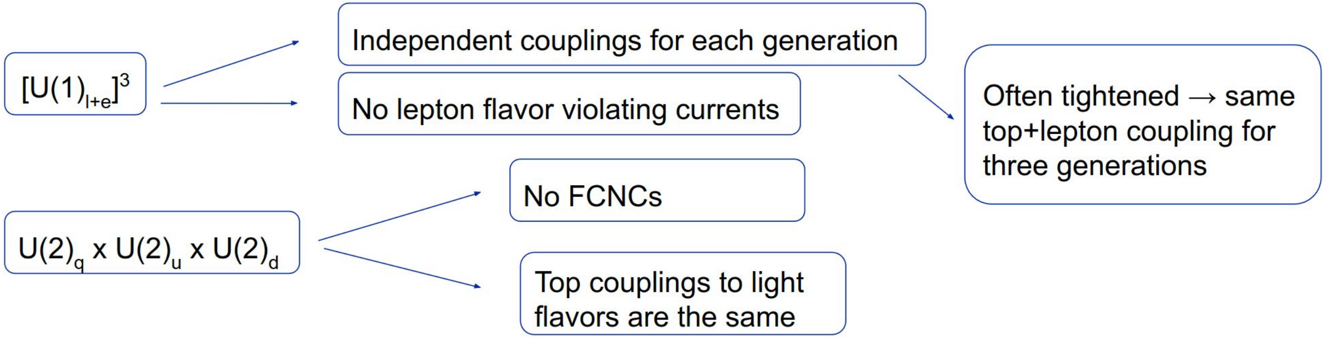


VBF production



- ○ Most stringents CP violations limits in ggH: excludes a pure CP-odd scenario in ggH with a significance of 2.4 s.t.d
- ○ Limits can be rotated to Warsaw bases with tools like *Rosetta*, *JHUGENLexicon*
- ○ Also combined with H->4l and ttH, H→γγ/ multilepton, analyses

Top dim6top basis



$[U(1)_{l+e}]^3$

Independent couplings for each generation

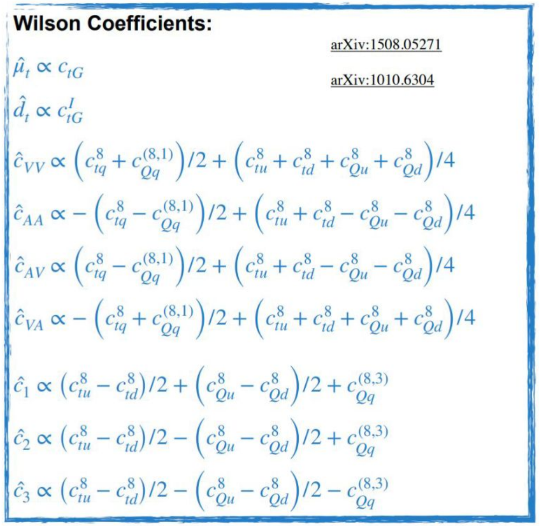
No lepton flavor violating currents

Often tightened → same top+lepton coupling for three generations

$U(2)_q \times U(2)_u \times U(2)_d$

No FCNCs

Top couplings to light flavors are the same



Wilson Coefficients:

arXiv:1508.05271

arXiv:1010.6304

$$\hat{\mu}_t \propto c_{tG}$$

$$\hat{d}_t \propto c^I_{tG}$$

$$\hat{c}_{VV} \propto \left(c^8_{tq} + c^{(8,1)}_{Qq}\right)/2 + \left(c^8_{tu} + c^8_{td} + c^8_{Qu} + c^8_{Qd}\right)/4$$

$$\hat{c}_{AA} \propto -\left(c^8_{tq} - c^{(8,1)}_{Qq}\right)/2 + \left(c^8_{tu} + c^8_{td} - c^8_{Qu} - c^8_{Qd}\right)/4$$

$$\hat{c}_{AV} \propto \left(c^8_{tq} - c^{(8,1)}_{Qq}\right)/2 + \left(c^8_{tu} + c^8_{td} - c^8_{Qu} - c^8_{Qd}\right)/4$$

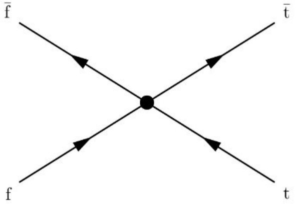
$$\hat{c}_{VA} \propto -\left(c^8_{tq} + c^{(8,1)}_{Qq}\right)/2 + \left(c^8_{tu} + c^8_{td} + c^8_{Qu} + c^8_{Qd}\right)/4$$

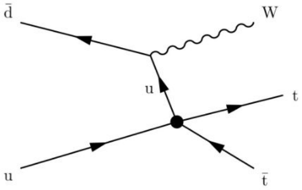
$$\hat{c}_1 \propto (c^8_{tu} - c^8_{td})/2 + \left(c^8_{Qu} - c^8_{Qd}\right)/2 + c^{(8,3)}_{Qq}$$

$$\hat{c}_2 \propto (c^8_{tu} - c^8_{td})/2 - \left(c^8_{Qu} - c^8_{Qd}\right)/2 + c^{(8,3)}_{Qq}$$

$$\hat{c}_3 \propto (c^8_{tu} - c^8_{td})/2 - \left(c^8_{Qu} - c^8_{Qd}\right)/2 - c^{(8,3)}_{Qq}$$

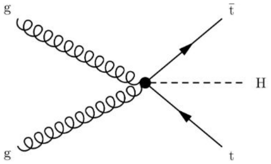
- 42 (+11 CP violating) independent operators
- Up to 75 if considering independent couplings to lepton generations

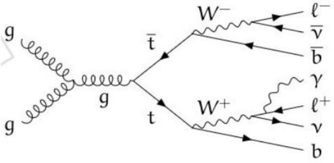




4-fermion operators
4-heavy-quark operators → 11 (+2 CPV)
Two-heavy-two-light operators →14 operators
Two-heavy-two-lepton operators → (8 + (3 CPV)) x 3

Heavy quark + boson operators → 9 (+ 6 CPV)

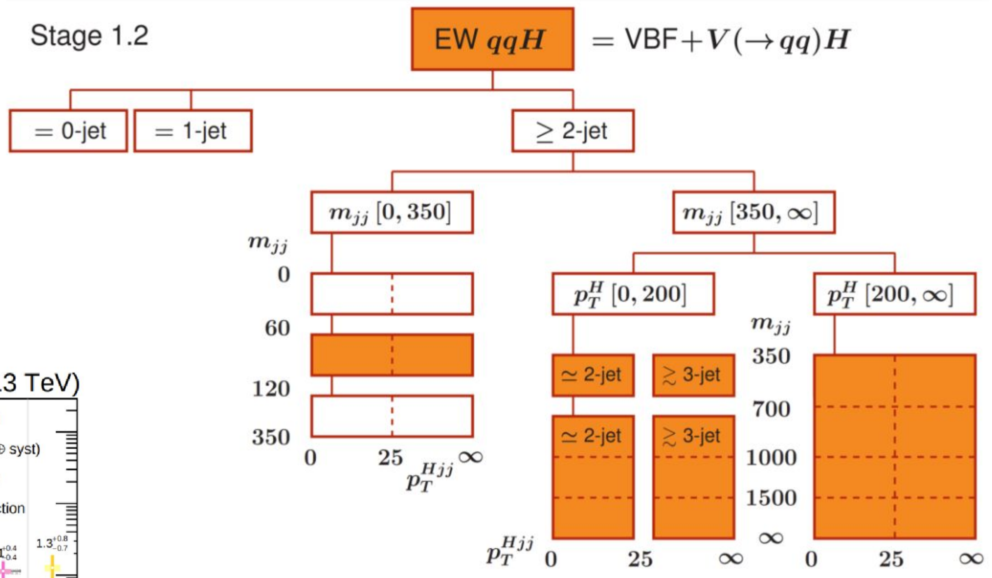


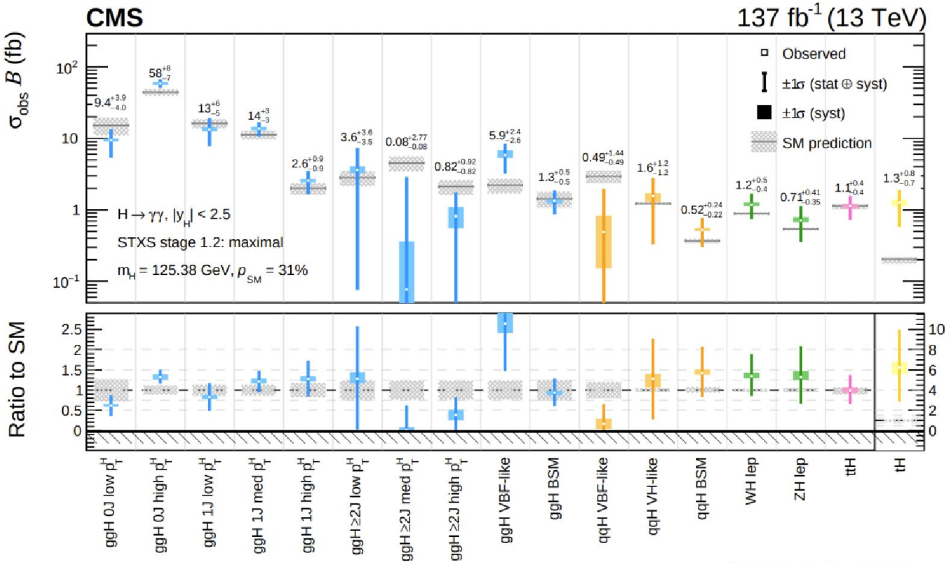


STXS framework

Template cross sections with binning motivated by

- Sensitivity to NP
- Avoidance of large theory uncertainties
- Close matching to experimental selections
- Common production mode binning across decay channels





[HIG-19-015](HIG-19-015)