Higgs EFTs and CP violation session - the three summary slides

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Higgs Hunting 2022 - 13th of September 2022

Higgs Effective Field Theories - summary

Growing number of EFT interpretations: from single final state interpretation to STXS to global fit w/ EW observables.

Single final state

$H \to \gamma\gamma$ differential cross-section JHEP 08 (2022) 027

Simultaneous fit to $p^{\gamma\gamma}$, Njets, mjj, $\Delta\Phi$jj, p^{j1}
4 CP-even and 4 CP-odd Wilson coefficients measured, one at a time, higher sensitivity when incl. quadratic terms for CP-odd

$H \to \gamma\gamma$ STXS HIGG-2020-16

Fit of 33 STXS bins in p_T^H, m_{jj}, N_{jets}, p_T^V targeting the production modes

Signal strength per STXS bin parametrisation
→ 34 Wilson coefficients measured in Warsaw basis

Higgs → 4l Phys. Rev. D 104 (2021) 052004

ggH+2jets, VBF, VH, ttH, tH

MELA observables.

Simultaneous measurement of up to five HVV, two Hgg, and two Htt couplings.

ttH or ttZ with Higgs→bb or Z→bb
CMS-TOP-21-003

Lorentz boosted Z or Higgs.

8 parameters of LO EFT constrained w/ large impact on boosted ttZ or ttH production (one at a time)

STXS (allows combination of several analyses with same phase space)

STXS Higgs combination ATLAS-CONF-2021-053

Principal component analysis to identify linear combinations of Wilson coefficients → choice of sensitive direction and rejection of flat directions

STXS Higgs combination CMS-PAS-HIG-19-005

Fit of stage 1 STXS bins.
Simultaneous fit to 8 Higgs Effective Lagrangian coefficients.

Higgs + EW global fit

Higgs + EW + precision observables global fit
ATL-PHYS-PUB-2022-037

ATLAS Higgs STXS measurement + unfolded fiducial cross section measurements of weak bosons + 8 EW observables from LEP/SLC

$\Gamma_Z, \sigma^0_{had}, R^0_\ell, A^{0,l}_{FB}$
$R^0_b, R^0_c, A^{0,b}_{FB}, A^{0,c}_{FB}$

$$\sigma^0_{had} = \frac{12\pi}{m_Z^2}\frac{\Gamma_{ee}\Gamma_{had}}{\Gamma_Z^2}$$

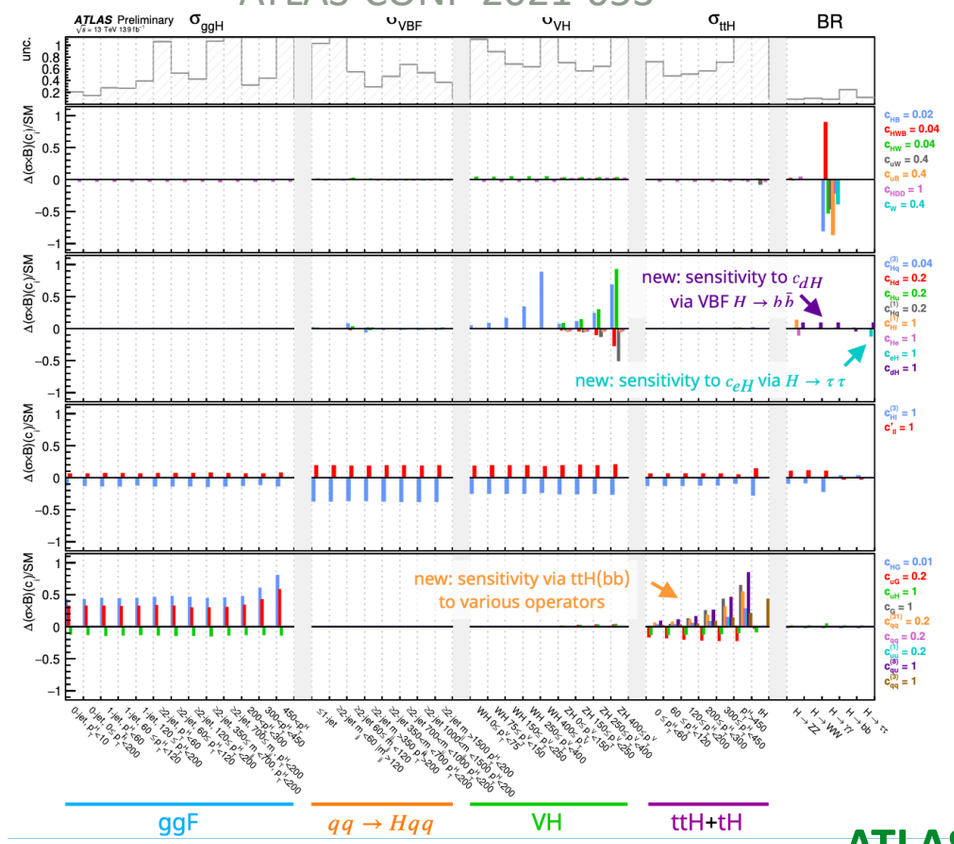
$$R^0_\ell = \frac{\Gamma_{had}}{\Gamma_{\ell\ell}}, R^0_q = \frac{\Gamma_{qq}}{\Gamma_{had}}$$

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

Higgs Effective Field Theories - a few plots

ATLAS - STXS combination

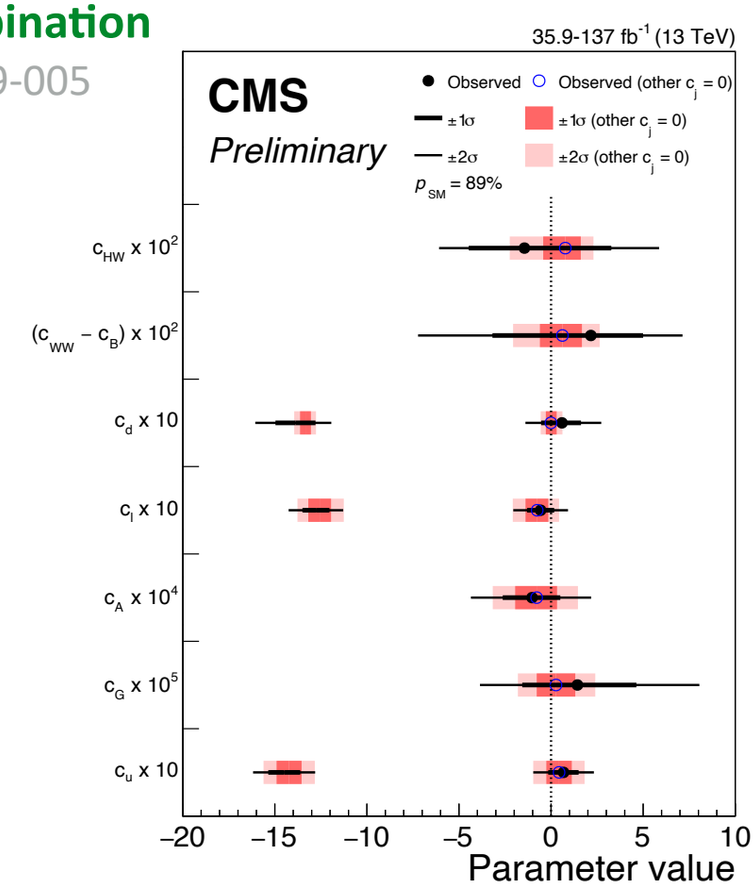
ATLAS-CONF-2021-053



CMS - STXS combination

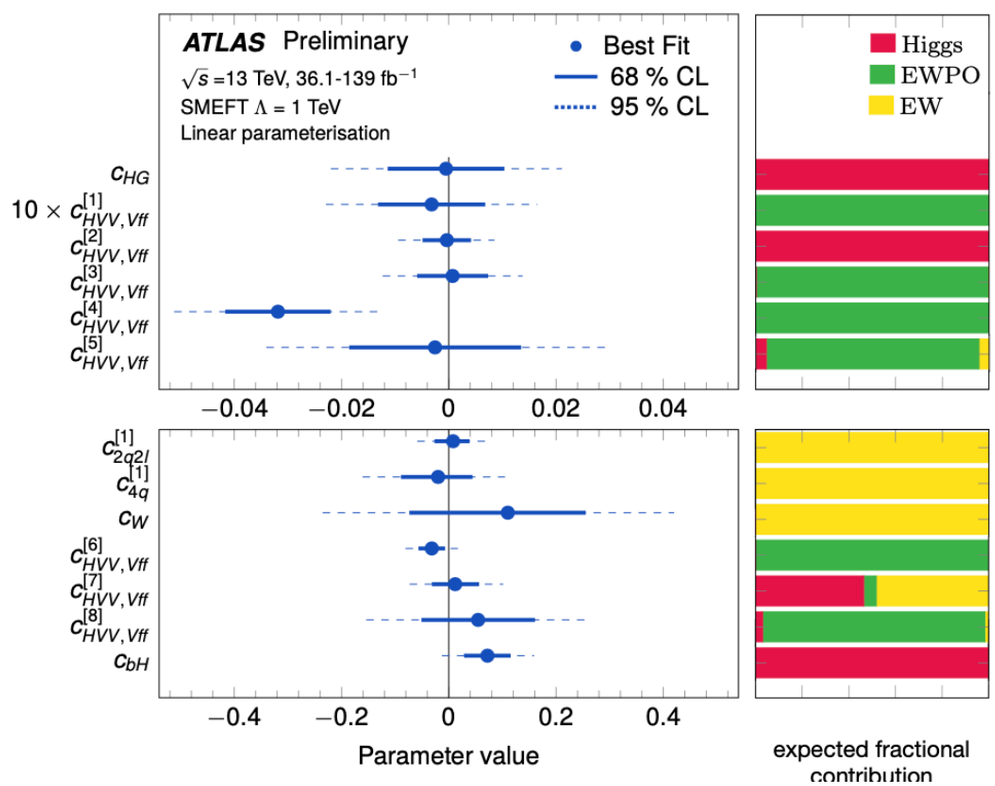
CMS-PAS-HIG-19-005

HEL Parameters	Definition
$c_A \times 10^4$	$c_A = \frac{m_W^2}{g'^2}\frac{f_A}{\Lambda^2}$
$c_G \times 10^5$	$c_G = \frac{m_W^2}{g_s^2}\frac{f_G}{\Lambda^2}$
$c_u \times 10$	$c_u = -v^2\frac{f_u}{\Lambda^2}$
$c_d \times 10$	$c_d = -v^2\frac{f_d}{\Lambda^2}$
$c_\ell \times 10$	$c_\ell = -v^2\frac{f_\ell}{\Lambda^2}$
$c_{HW} \times 10^2$	$c_{HW} = \frac{m_W^2}{2g}\frac{f_{HW}}{\Lambda^2}$
$(c_{WW} - c_B) \times 10^2$	$c_{WW} = \frac{m_W^2}{g}\frac{f_{WW}}{\Lambda^2}$

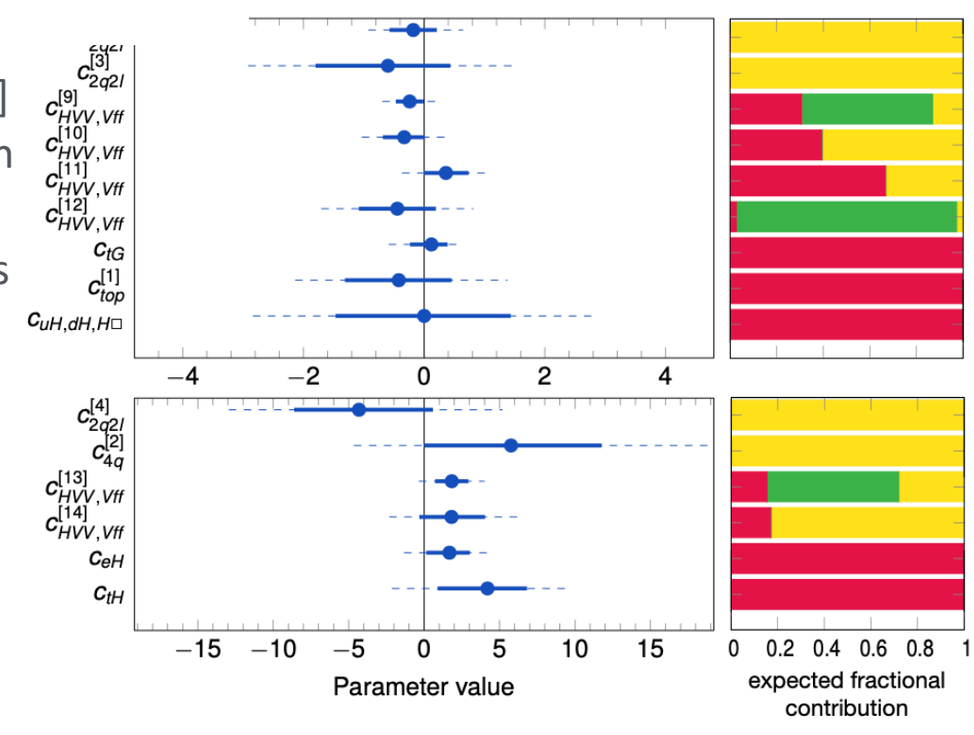


ATLAS - STXS + EW + precision observables combination

ATL-PHYS-PUB-2022-037

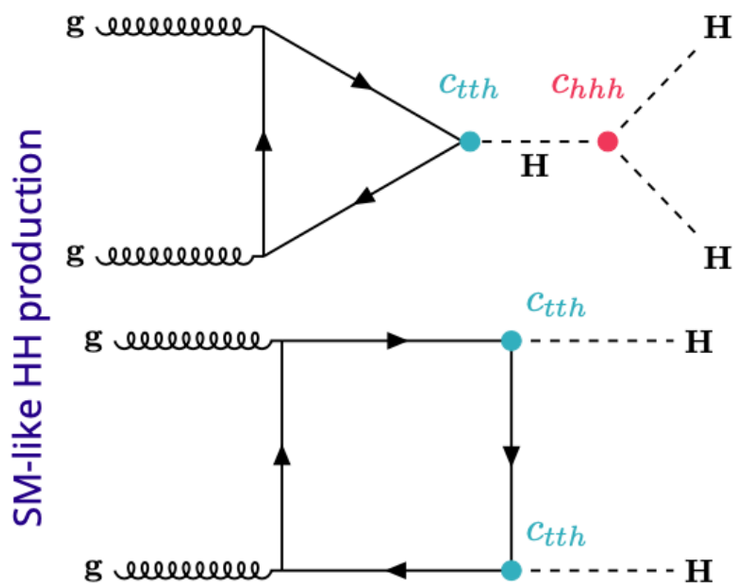


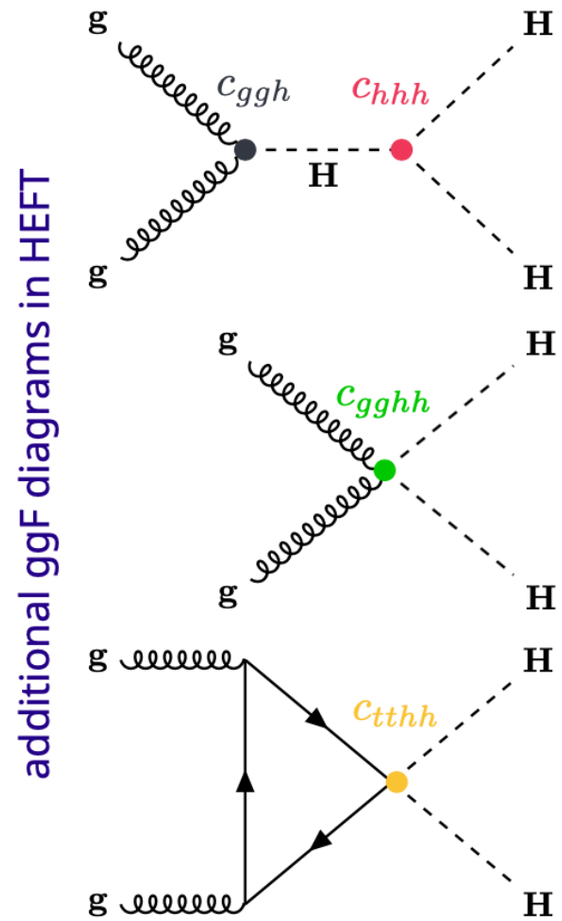
CHVV, Vff [4] excess driven by F/B asymmetries

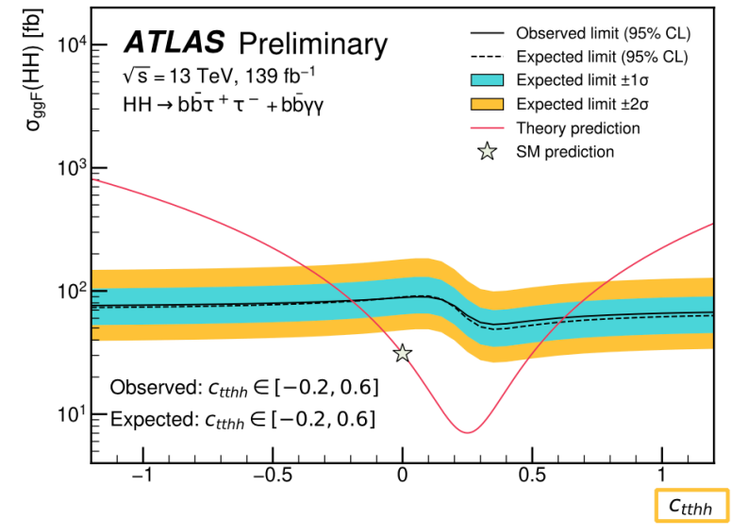


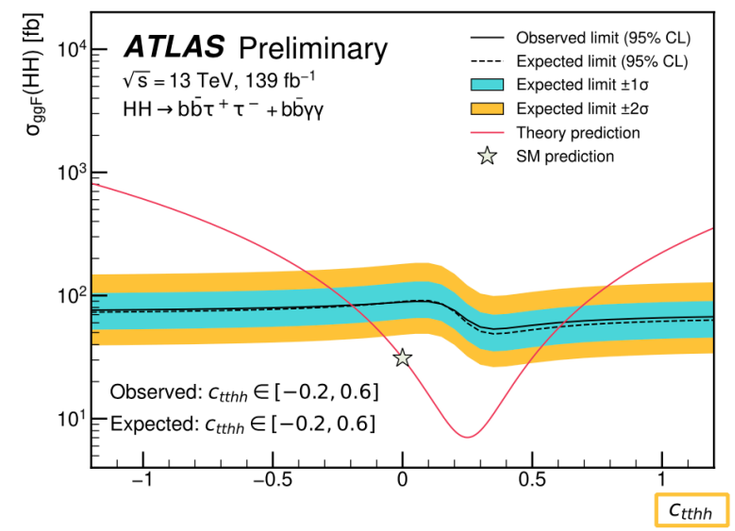
EFT - di-Higgs searches

EFTs to modelise the non-SM di-Higgs diagrams.





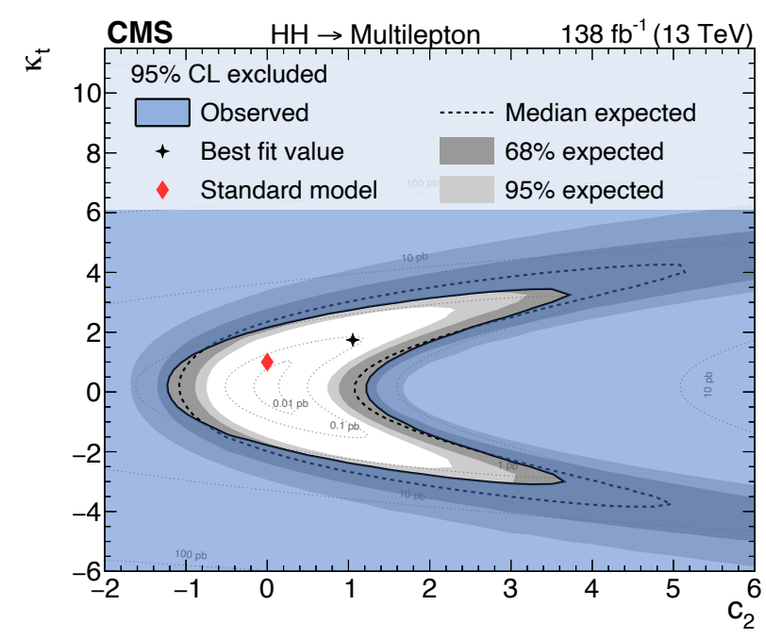




bbττ + bbγγ combination: **Cgghh [-0.3, 04] obs. ([-0.3, 0.3] exp.)**
Ctthh [-0.2, 0.6] obs. and exp., ATL-PHYS-PUB-2022-019

HEFT operators used, 7 benchmarks.

Unlike in SMEFT, the couplings affect the Higgs boson pairs and not single Higgs bosons → suitable for HH interpretation.



bbbb Phys. Rev. Lett. 129 (2022) 081802 and **WWWW, WWττ ττττ in multi-lepton final states** CMS-HIG-21-002 sub. to JHEP: (κ_λ, κ_t, C2(ttHH), C2g(ggHH), Cg(ggHH)), 12 and 20 benchmark points, **−1.05 < C2 < 1.48 obs. (−0.96 < C2 < 1.37 exp.).**

CP violation - HVV couplings

arXiv:2202.069230

Tree level CP-even coupling (=0 if absent in SM)

CP-even anomalous higher order couplings

$$\mathscr{A}(HVV) \simeq \left[a_1^{VV} + \frac{k_1^{VV} q_1^2 + k_2^{VV} q_2^2}{(\Lambda_1^{VV})^2} + \frac{k_3^{VV}(q_1+q_2)^2}{(\Lambda_Q^{VV})^2} \right] m_V^2 \varepsilon_{V1}^* \varepsilon_{V2}^*$$

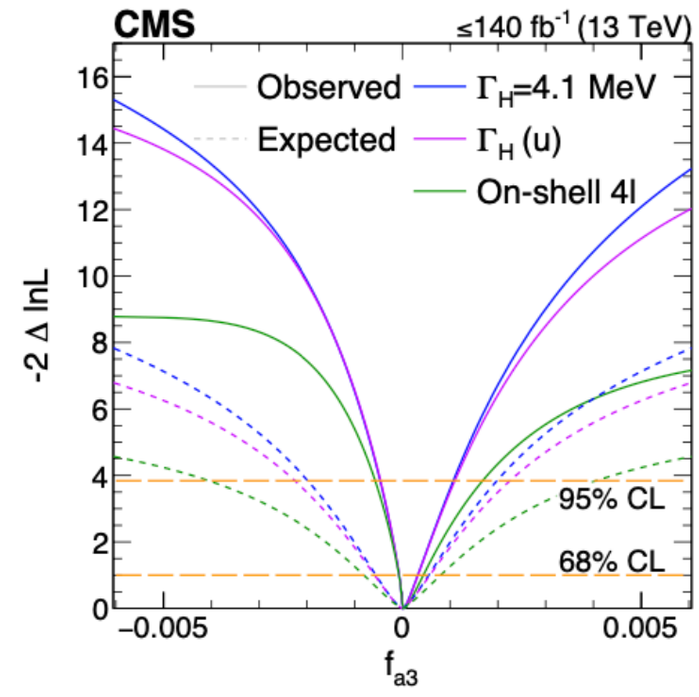
$$+ a_2^{VV} f_{\mu\nu}^{*(1)} f^{*(2)\mu\nu} + a_3^{VV} f_{\mu\nu}^{*(1)} \bar{f}^{*(2)\mu\nu} \ ,$$

CP-even anomalous coupling

CP-odd anomalous coupling

CMS: H→ZZ→4l: off-shell Higgs production can provide additional sensitivity

→ CP-odd anomalous coupling constrained to [-4.6,11] × 10^{-4} at 95% CL.



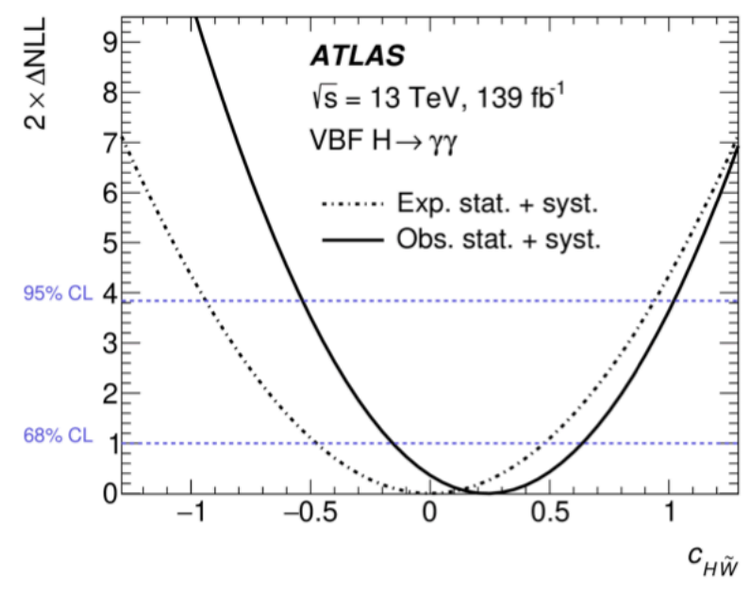
ATLAS: VBF, H → $\gamma\gamma$

Optimal observable with reconstructed ME from Higgs and VBF jets momenta

$C_{H\tilde{W}}$ ∈ [-0.55-1.02] at 95%CL (no add. sensitivity when add. quadratic term)

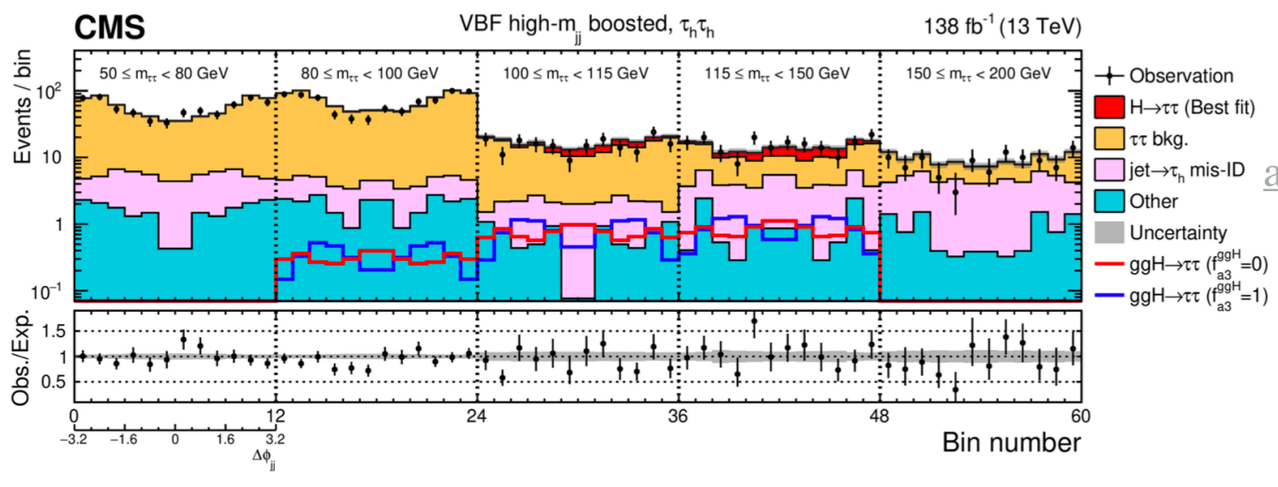
Combination with H→ττ

CERN-EP-2022-134



CMS: H→ττ, VFB and ggH with 2 jets - azimuthal angle between 2 jets / MELA obs.

Combination with H→4l and H→γγ: pure CP-odd coupling to gluons is excluded at 2.4σ



arxiv:2205.05120

CP violation - tau and top Yukawa couplings

Generalised Yukawa coupling, CP violation can occur at tree level

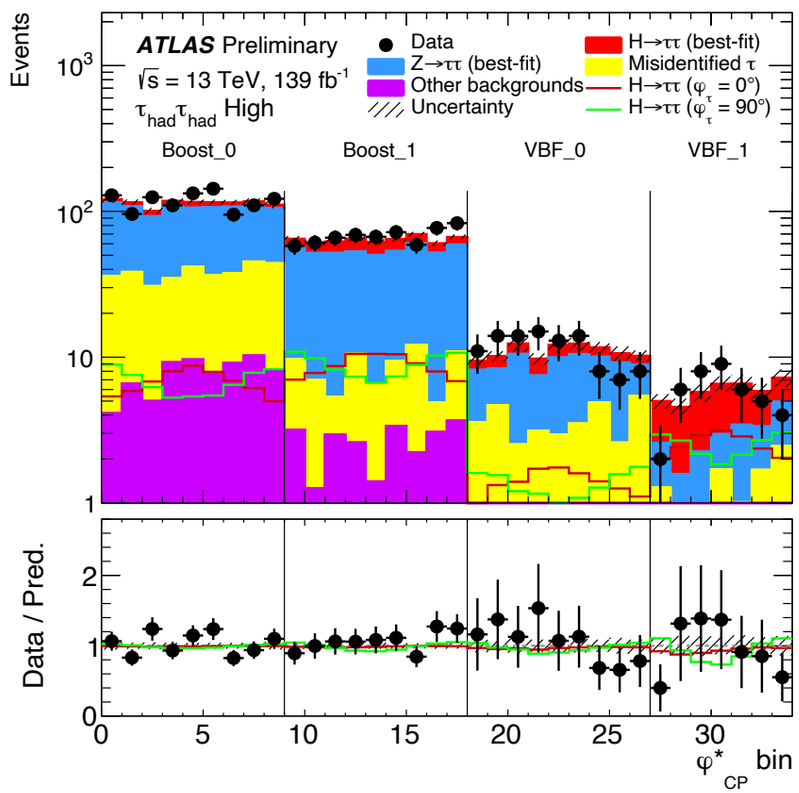
$$L_Y = -\frac{m_l \phi}{\nu}(\kappa_l \overline{\psi_l}\psi_l + \tilde{\kappa}_l \overline{\psi_l} i\gamma_5 \psi_l)$$

$$f_{cp}^{Hll} = \frac{|\tilde{\kappa}_l|^2}{|\kappa_l|^2 + |\tilde{\kappa}_l|^2} = \sin^2(\alpha^{Hll})$$

Angle between tau decay planes gives access to α(Hll)

Several techniques depending on τ decay mode $\mu^{\pm}, e^{\pm}, \pi^{\pm}, \rho^{\pm}, a_1^{1pr,3pr}$

ATLAS-CONF-2022-032



CMS → **pure CP-odd hypothesis excl. at 3.0σ (2.6σ)**

(JHEP 06 (2022) 012) → **α(Hττ) = -1 ± 19°**

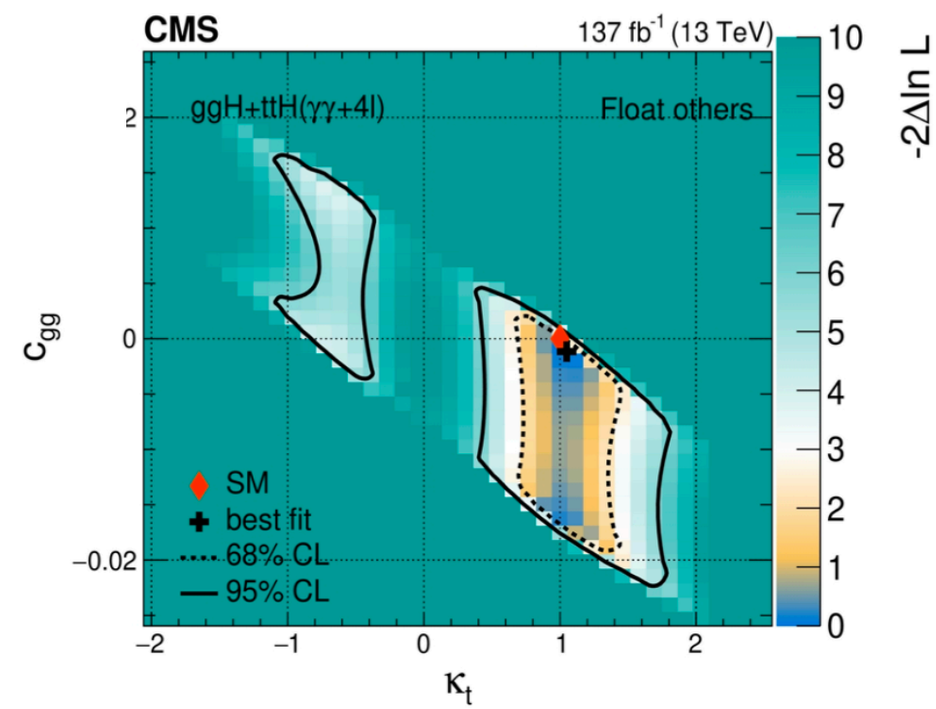
ATLAS → **pure CP-odd hypothesis excl. at 3.4σ (2.1σ)**

(ATLAS-CONF-2022-032) → **α(Hττ) = 9 ± 16°**

(VBF + ggH boosted pT>100 GeV)

Top Yukawa CP structure can be probed in $t\bar{t}H, H \to 4l, \gamma\gamma$ and ggH loop with top quark dominance

Phys. Rev. D 104 (2021) 052004



CMS → pure CP-odd hypothesis excl. at 3.2σ

Phys. Rev. D 104 (2021) 052004

ATLAS → pure CP-odd hypothesis excl. at 3.9σ (ttH,$\gamma\gamma$)

Phys. Rev. lett. 125 (2020) 061802

→ pure CP-odd hypothesis excl. at 1.2σ (ttH,bb)

ATLAS-CONF-2022-016