Probing the CP nature of the top-Higgs Yukawa coupling in ttH and tH events with H→bb using the ATLAS detector

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1.Motivation

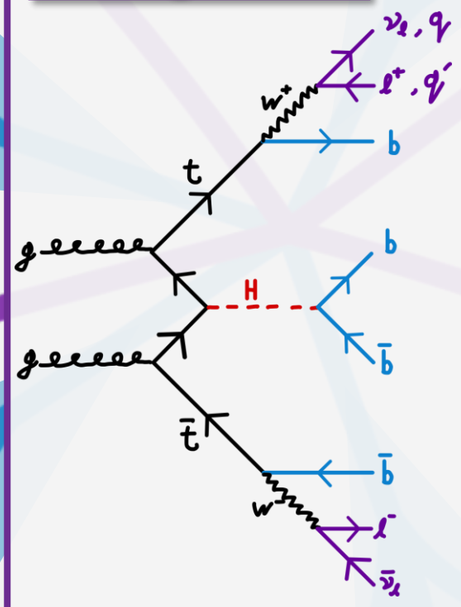
- → The **ttH** process allows for direct access to the **top-Higgs Yukawa coupling**.
- → Previous analyses have measured CP of the interaction in ttH events with **H→γγ** [1]
- → This analysis gives **a first measurement** of the CP properties in the **H→ bb decay channel** [2]

2.CP Mixing

$$\mathcal{L}'_{t\bar{t}H} = -\kappa'_t y_t \Phi \bar{\psi}_t (\cos\alpha + i\gamma_5 \sin\alpha)\psi_t$$

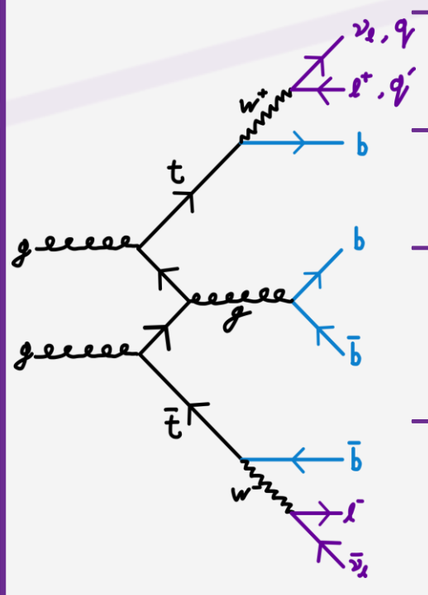
- → In the SM the Higgs boson is a **CP-even** scalar particle, a pure **CP-odd** coupling has been excluded at 95% confidence level [1].
- → Admixtures of CP-even and CP-odd are still allowed experimentally.
- → Mixing between CP-even and CP-odd couplings is parametrised in terms of a **mixing angle** α and **coupling strength modifier** κ'_t [3]

3.Signal



- → Analysis targets **ttH** events with H → bb
- → **tWH** and **tHjb** processes are also considered as signal.
  - → The tH cross section exhibits a strong dependence on κ'_t and α.
- → Events split into channels based on decay products of the top quark pair:
  - → Dilepton channel, 4 ***b*-tagged jets**, 2 charged **leptons**
  - → l+jets channel, 6 jets including 4 ***b*-tagged jets**, 1 charged **lepton**

4.Background



- → Analysis is dominated by $t\bar{t}$ background.
- → $t\bar{t}$ **+≥ 1*b*** component has the largest contribution.
- → Systematics on $t\bar{t}$ +≥ 1b background **limit the sensitivity** of the analysis.
- → Separation of signal and background improved by using **Classification BDT** to separate $t\bar{t}H$ from $t\bar{t}$ +≥ 1b

5.Analysis Strategy

- → CP Mixing angle and coupling strength are extracted from profile likelihood fit .
- → **3b Control Regions (CR)**: fit yield
- → **4j Signal Regions (SR)**: fit b_4
- → **4j Non-reconstructed* CR**: fit $\Delta\eta_{ll}$
- → **5j CR**: fit ΔR_{bb}
- → **6j SR**: fit $b_2^{t\bar{t}H}$
- → **6j boosted SR**: fit Classification BDT

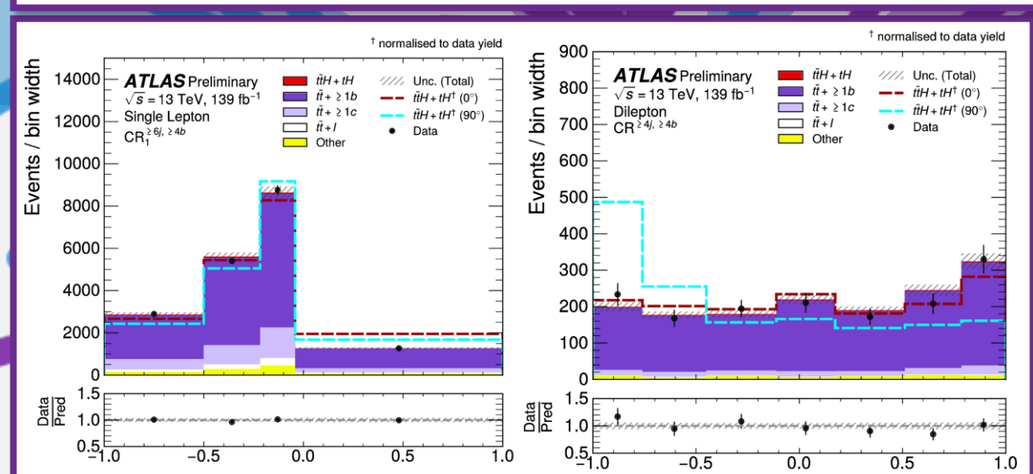
*** Neutrino weighting used in top quark reconstruction fails for some events**

6.CP Variables

- → Sensitivity to α and κ'_t obtained by fitting **CP-sensitive observables.**
- → Observables exploit **angular and kinematic differences** in events caused by CP effects
- → Observables b_4 and $b_2^{t\bar{t}H}$ found to be most sensitive to use in analysis [4].
- → l+jets: $b_2^{t\bar{t}H}$ used:
  - → Computed in ttH rest frame to **enhance sensitivity**
- → Dilepton: b_4 and $\Delta\eta_{ll}$ used:
  - → $\Delta\eta_{ll}$: Used for events where **top reconstruction fails**, acts a **proxy for pseudorapidity difference** between top quarks

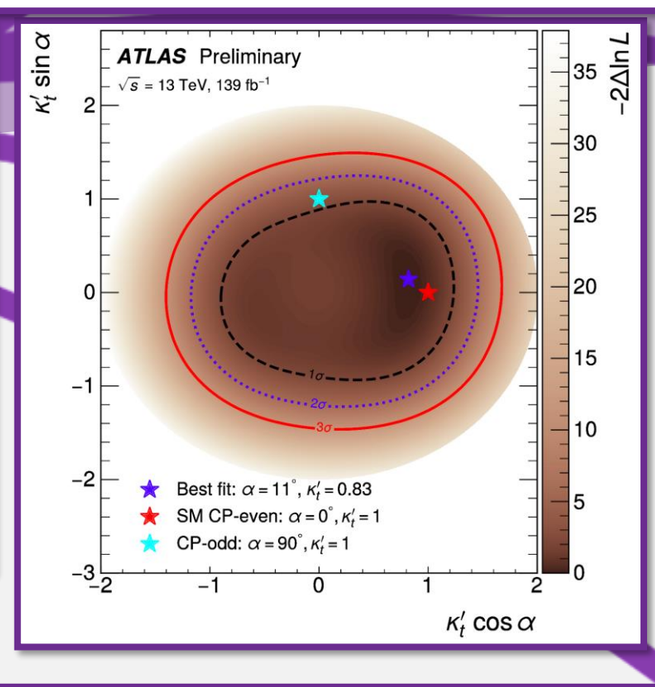
Region		Dilepton PSR$^{\geq 4j,\geq 4b}$	Dilepton CR$^{\geq 4j,3b}_{\text{hi}}$	Dilepton CR$^{\geq 4j,3b}_{\text{lo}}$	Dilepton CR$^{3j,3b}_{\text{hi}}$	ℓ+jets PSR$^{\geq 6j,\geq 4b}$	ℓ+jets CR$^{5j,\geq 4b}_{\text{hi}}$	ℓ+jets CR$^{5j,\geq 4b}_{\text{lo}}$	ℓ+jets PSR$_{\text{boosted}}$
N_{jets}			≥ 4		= 3	≥ 6	= 5		≥ 4
$N_{b-\text{tag}}$	@85%		–				≥ 4		
	@77%		–				–		≥ 2†
	@70%	≥ 4	= 3				≥ 4		–
	@60%	–	= 3	< 3	= 3	–	≥ 4	< 4	–
$N_{\text{boosted cand.}}$			–				0		≥ 1

Channel (PSR)	Final SRs and CRs	Classification BDT selection	Fitted observable
Dilepton (PSR$^{\geq 4j,\geq 4b}$)	CR$^{\geq 4j,\geq 4b}_{\text{no-reco}}$	–	$\Delta\eta_{\ell\ell}$
	CR$^{\geq 4j,\geq 4b}$	BDT∈ [−1, −0.086)	b_4
	SR$^{\geq 4j,\geq 4b}_1$	BDT∈ [−0.086, 0.186)	b_4
	SR$^{\geq 4j,\geq 4b}_2$	BDT∈ [0.186, 1]	b_4
ℓ+jets (PSR$^{\geq 6j,\geq 4b}$)	CR$^{\geq 6j,\geq 4b}_1$	BDT∈ [−1, −0.128)	b_2
	CR$^{\geq 6j,\geq 4b}_2$	BDT∈ [−0.128, 0.249)	b_2
	SR$^{\geq 6j,\geq 4b}$	BDT∈ [0.249, 1]	b_2
ℓ+jets (PSR$_{\text{boosted}}$)	SR$_{\text{boosted}}$	BDT∈ [−0.05, 1]	Classification BDT score



$$b_2^f(i,j) = \frac{(\vec{p}_i^{\,f} \times \hat{k}_z).(\vec{p}_j^{\,f} \times \hat{k}_z)}{|\vec{p}_i^{\,f}||\vec{p}_j^{\,f}|}$$

$$b_4^f(i,j) = \frac{p_{i,z}^f \; p_{j,z}^f}{|\vec{p}_i^{\,f}||\vec{p}_j^{\,f}|}$$



7.Results

- → The best fit point gives a **mixing angle of $\alpha = 11^{\circ}{}^{+56^{\circ}}_{-77^{\circ}}$** and **coupling strength modifier $\kappa'_t = 0.83^{+0.30}_{-0.46}$**
- → A pure CP-odd coupling is **disfavoured at 1.2 σ** significance.

References:
[1] ATLAS Collaboration, "CP Properties of Higgs Boson Interactions with Top Quarks in the ttH and tH Processes Using H→γγ with the ATLAS Detector", Phys. Rev. Lett. 125, 061802
[2] ATLAS Collaboration, "Probing the CP nature of the top-Higgs Yukawa coupling in ttH and tH events with H →bb using the ATLAS detector at the LHC", ATLAS-CONF-2022-016
[3] F. Demartin, F. Maltoni, K. Mawatari, B. Page & M. Zaro, "Higgs characterisation at NLO in QCD: CP properties of the top-quark Yukawa interaction", Eur. Phys. J. C 74, 3065 (2014)
[4] J. F. Gunion and X.-G.He, "Determining the *CP* Nature of a Neutral Higgs Boson at the CERN Large Hadron Collider", Phys. Rev. Lett. 76 (1996) 4468

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