$\mathcal{CP}$-properties of the top-Yukawa coupling at the LHC: a global perspective

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in collaboration with
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Introduction

Effective model

Relevant processes

Global fit

Conclusions

Motivation

Current situation:

- no direct evidence for BSM physics at LHC yet,
- most known particles studied intensively confirming SM predictions.

Where to look for new physics? Obvious candidate: the **Higgs boson**

- Higgs boson properties still leave room for deviations from SM.
- Deviations could be connected to open problems
  e.g. baryon asymmetry of the universe

How much do we know already about the discovered Higgs boson?

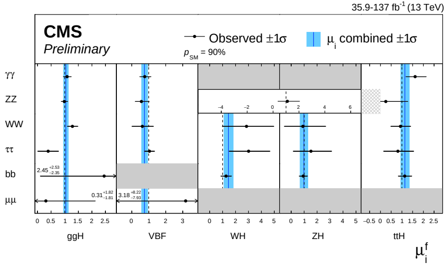
Higgs measurements: examples

- Higgs mass: [Aad et al.,1503.07589]

$$M_h^{\rm exp} = 125.08 \pm 0.21\ (\text{stat.}) \pm 0.11\ (\text{sys.})\ \text{GeV}$$

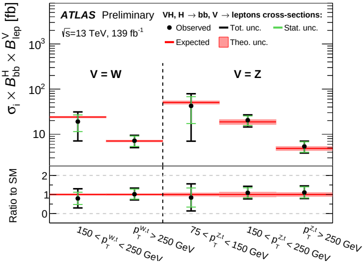
- Coupling measurements:

  [CMS-PAS-HIG-19-005]



- Kinematic distributions:

  [ATLAS-CONF-2020-006]



Higgs $\mathcal{CP}$ properties

- Pure $\mathcal{CP}$-odd Higgs excluded,
- but Higgs could still be $\mathcal{CP}$-admixture,

$$H = \cos\alpha \cdot H_{\mathcal{CP}\text{-even}} + \sin\alpha \cdot H_{\mathcal{CP}\text{-odd}}.$$

- Most Higgs-$\mathcal{CP}$ measurements focus on Higgs vector-boson couplings,
- but typical BSM models predict largest $\mathcal{CP}$-odd component in the top-Yukawa coupling.

$\rightarrow$ Study $\mathcal{CP}$-properties of top-Yukawa coupling in effective model.

Effective model

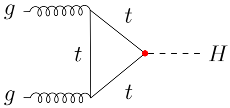
- Top-Yukawa Lagrangian (generated by $1/\Lambda^2(\Phi^\dagger\Phi)Q_L\tilde{\Phi}t_R$ operator),

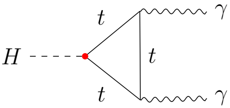
$$\mathcal{L}_{\text{yuk}} = -y_t^{\text{SM}}\bar{t}\left(c_t + i\gamma_5\tilde{c}_t\right)tH.$$

c_t: $\mathcal{CP}$-even coupling; $\tilde{c}_t$: $\mathcal{CP}$-odd coupling

- Can allow for additionally free
  - $c_V \rightarrow$ rescaling HVV couplings,
  - $\kappa_g \rightarrow$ rescaling $gg \rightarrow H$,
  - $\kappa_\gamma \rightarrow$ rescaling $H \rightarrow \gamma\gamma$.

Relevant processes: $gg \to H$ & $H \to \gamma\gamma$



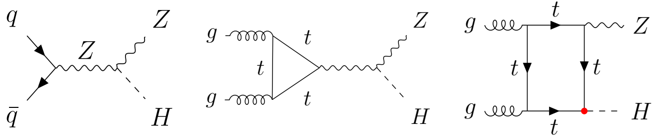


- top-Yukawa influences
  - $gg \to H$ signal strength

$$\kappa_g^2 \equiv \left.\frac{\sigma_{gg\to H}}{\sigma_{gg\to H}^{\mathrm{SM}}}\right|_{M_t\to\infty} = c_t^2 + \frac{9}{4}\tilde{c}_t^2 + \ldots,$$

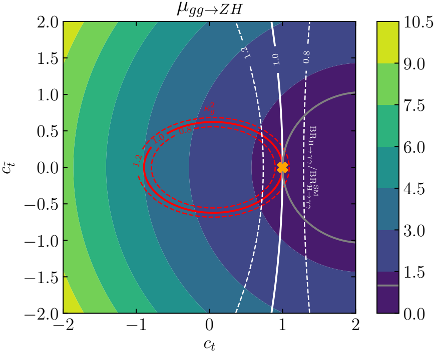
    calculate κ_g either in terms of c_t and $\tilde{c}_t$ or treat it as free parameter ($\to$ undiscovered colored BSM particles),
  - kinematic shapes not sensitive yet, (future potential: $\Delta\phi_{jj}$ in $gg \to H + 2j$)
- similarly $H \to \gamma\gamma$.

Relevant processes: ZH production



Total rate:

- Experimental measurement: $pp \to ZH$,
- $\sigma^{\text{SM}}_{q\bar{q}\to ZH} \approx 6\sigma^{\text{SM}}_{gg\to ZH}$,
- but $\sigma_{gg\to ZH}$ can be significantly enhanced.



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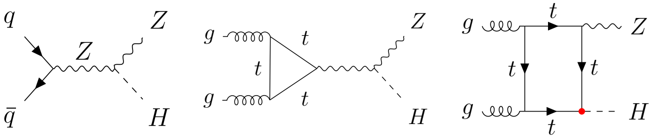

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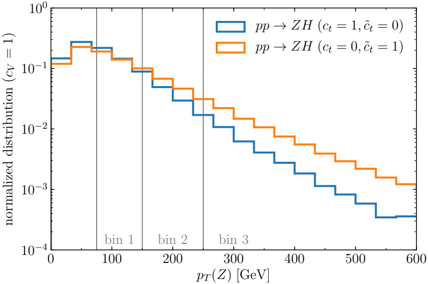
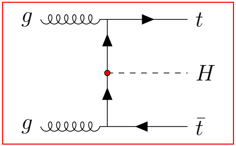
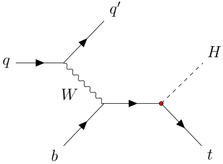
Kinematic shapes:

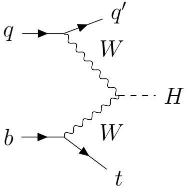
- Z p_T-shape sensitive to Higgs $\mathcal{CP}$-properties,
- use STXS bins as additional input.



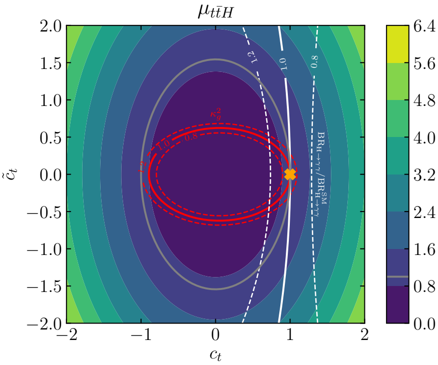
Relevant processes: ttH and tH production







- $t\bar{t}H$ and tH difficult to disentangle $\rightarrow$ combination of both measured,
- $\sigma^{\mathsf{SM}}_{t\bar{t}H} \approx 7\sigma^{\mathsf{SM}}_{tH}$,
- but $\mathcal{CP}$-odd Yukawa coupling can enhance σ_{tH}.



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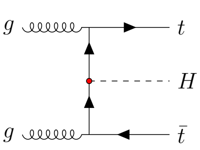

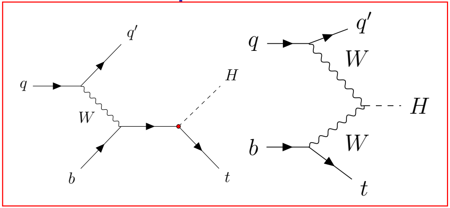

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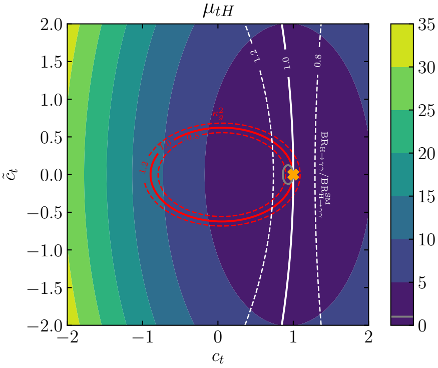
Kinematic shape:

- no measurements yet.

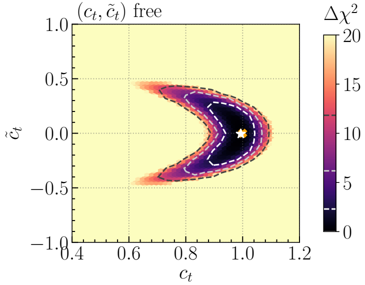


Fit setup

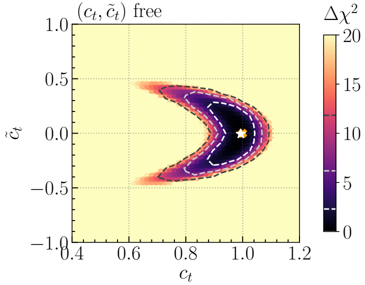
- Input:
  - all relevant Higgs measurements (latest April results not yet included),
  - if available, included all uncertainty correlations,
- consider three models:
  1. $(c_t, \tilde{c}_t)$ free,
  2. $(c_t, \tilde{c}_t, c_V)$ free,
  3. $(c_t, \tilde{c}_t, c_V, \kappa_g, \kappa_\gamma)$ free,
- random fit with $\mathcal{O}(10^7 - 10^8)$ points,
- fit performed using `HiggsSignals`.

All results preliminary!

Fit results


$(c_t, \tilde{c}_t)$ free
$\Delta\chi^2$
20
15
10
5
0
1.0
0.5
0.0
−0.5
−1.0
$\tilde{c}_t$
0.4
0.6
0.8
1.0
1.2
c_t

Fit results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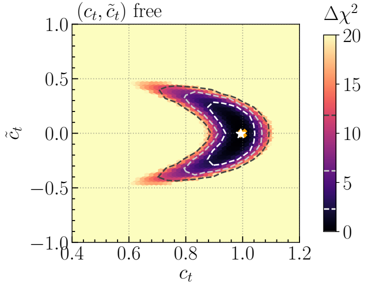

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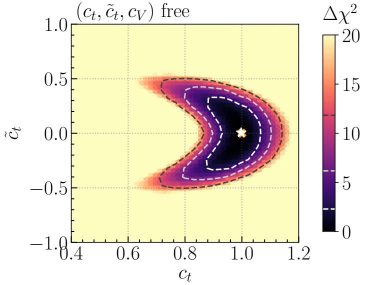

$(c_t, \tilde{c}_t, c_V)$ free
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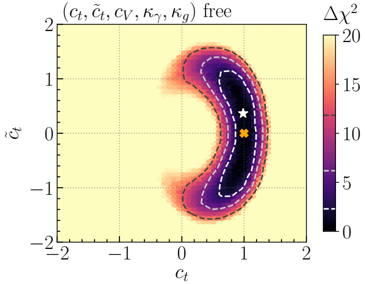

$(c_t, \tilde{c}_t, c_V, \kappa_\gamma, \kappa_g)$ free
$\Delta\chi^2$
20
15
10
5
0
2
1
0
−1
−2
c_t
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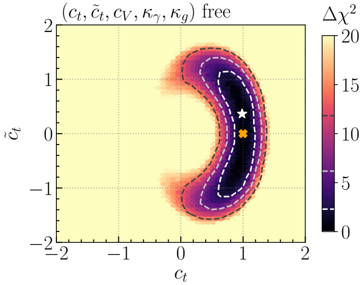
Influence of specific observables



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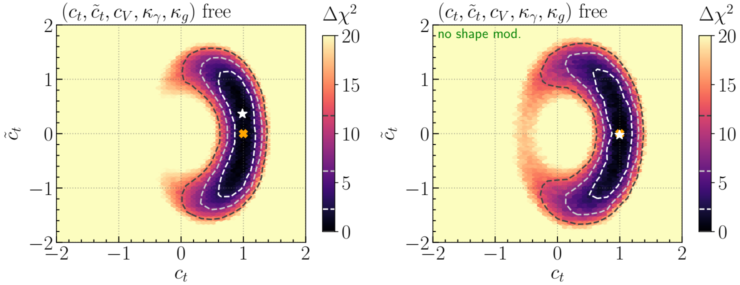

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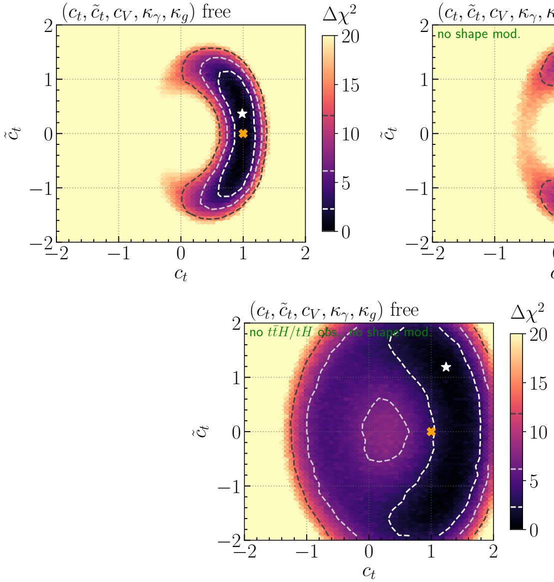

How to tighten the constraints?

- Best fit-point very close to SM,
- most general model still leaves room for sizeable $\mathcal{CP}$-odd coupling,
- how can we constrain this model further?

$\rightarrow$ Most promising candidate: improved tH, ttH measurements.

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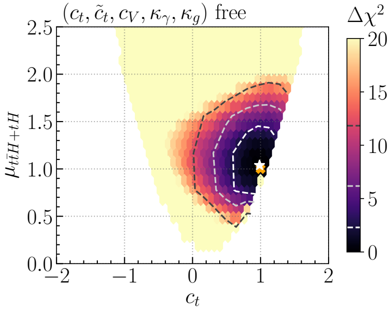

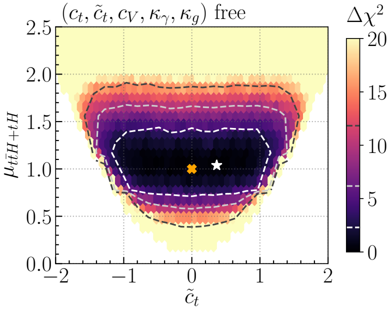

$\rightarrow$ Combined measurement of *tH* and *ttH* has no discrimination power regarding $\tilde{c}_t$.

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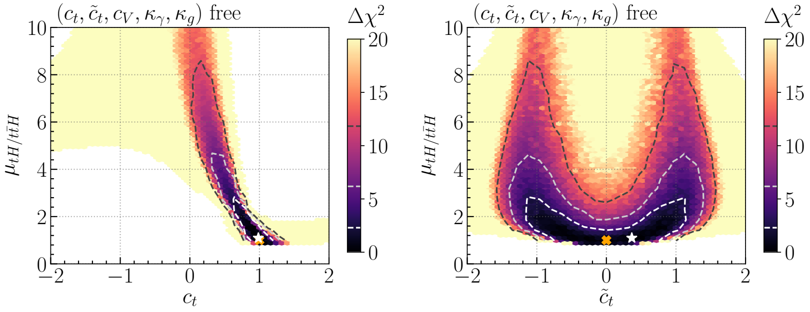

→ Need to disentangle tH and ttH!

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Initial question

How much constrained is a $\mathcal{CP}$-odd component of the top-Yukawa coupling already?

$\rightarrow$ global fit to all relevant LHC data:

- Used effective model with generalized top-Yukawa interaction,
- included total and differential cross-section measurements,
- fit results:
  - strong constraints from $gg \rightarrow H$ and $H \rightarrow \gamma\gamma$,
  - sizable $\mathcal{CP}$-odd coupling allowed if κ_g and κ_γ are varied independently,
- future disentanglement of ttH and tH could further constraint $\mathcal{CP}$-odd coupling.

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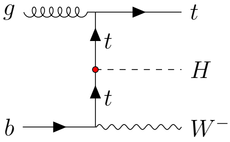
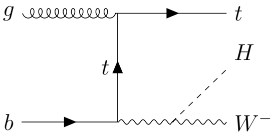
Thanks for your attention!

tWH production





- interferes with $t\bar{t}H$ production,
- $\sigma^{\text{SM}}_{t\bar{t}H} \approx 34\sigma^{\text{SM}}_{tWH}$,
- but non-negligible contribution in $\mathcal{CP}$-odd case: $\sigma^{\mathcal{CP}\text{-odd}}_{t\bar{t}H} \approx 3.5\sigma^{\mathcal{CP}\text{-odd}}_{tWH}$,

$\rightarrow$ fully taken into account in numerical analysis.

$\mathcal{CP}$ constraints from dedicated $t\bar{t}H$, tH analyses

[2003.10866, CMS; 2004.04545, ATLAS]

- Targeted $t\bar{t}H$ and tH with $H \to \gamma\gamma$,
- exploited kinematic distributions,
- enhanced $\mathcal{CP}$ sensitivity using BDTs.