LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

Measuring the CP structure of the top Yukawa coupling in ttH events at the LHC

Emanuel Gouveia, António Onofre, Ricardo Gonçalo
(e.gouveia@cern.ch)

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1.
Motivation for CP measurement in ttH

Motivation for CP measurement in ttH

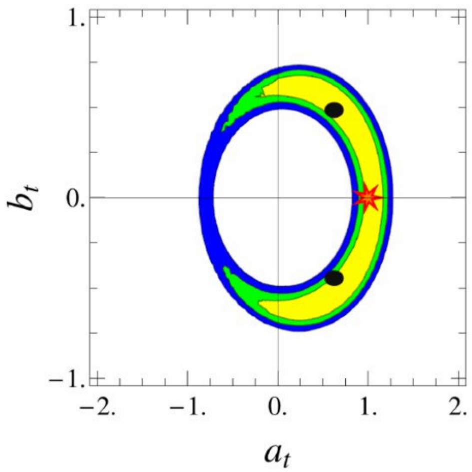
- ttH production recently observed by ATLAS and CMS, directly confirming the top-Higgs coupling!
  (Phys. Lett. B 784 (2018) 173, Phys. Rev. Lett. 120, 231801)

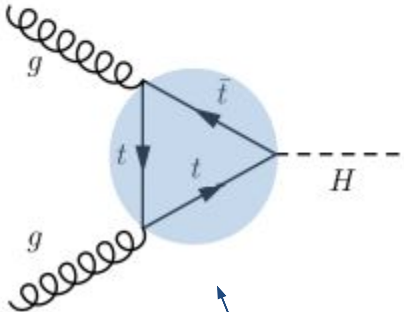
- Need to confirm the structure of this coupling. One possible departure from SM: CP-mixture

$$\mathcal{L} = \kappa\, y_t\, \bar{t}\,(\cos\alpha + i\gamma_5 \sin\alpha)\, t\, h$$

Motivation for CP measurement in ttH

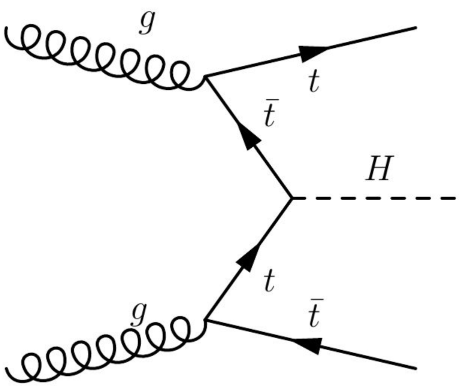
(Phys. Rev. D 92, 015019, 2015)





new physics can be "conspiring" in the loop

- Indirect constraints exist:
  (Phys. Rev. D 92, 015019, 2015;
  JHEP 1802 (2018) 073)
  - electron dipole moment
  - LHC Run I data, including ggF Higgs production
- Doesn't mean we should settle
- Need a direct measurement, for which ttH at the LHC is the best candidate

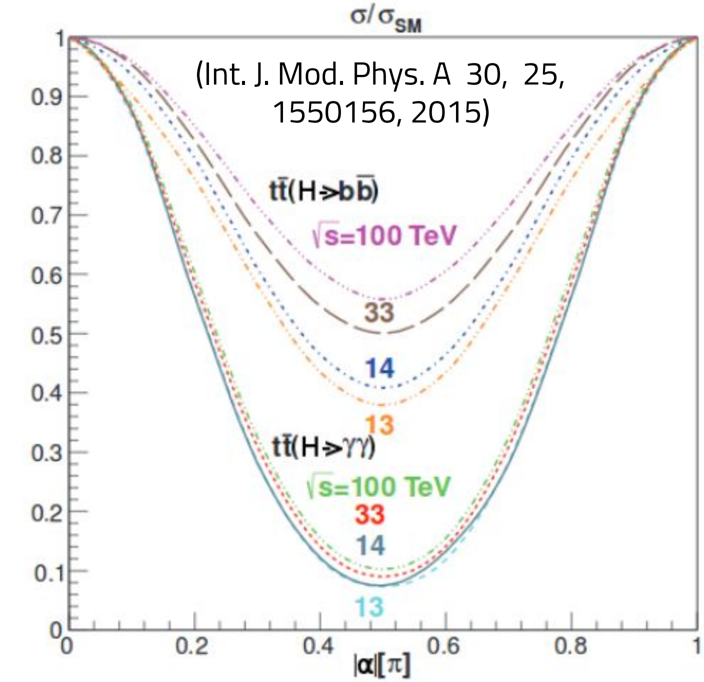


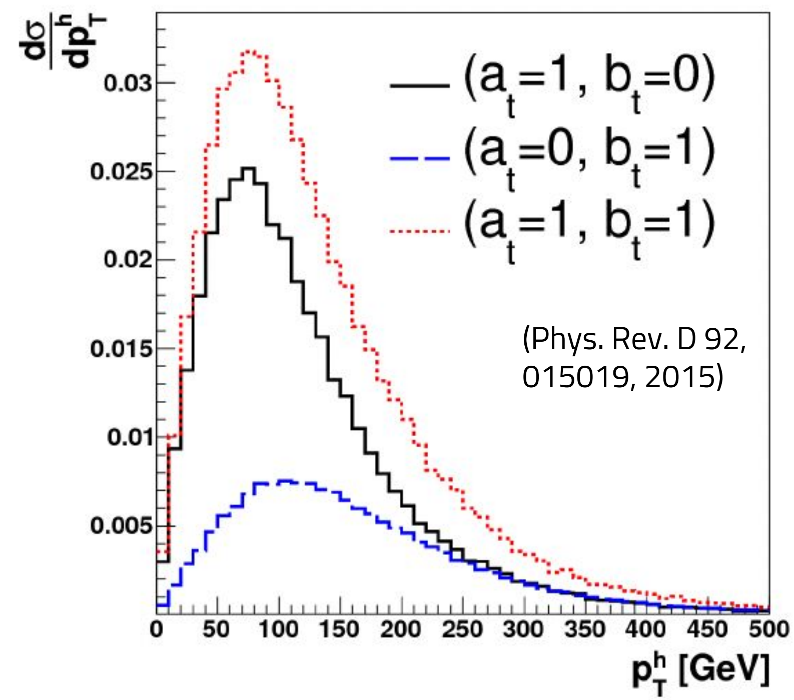
2.
Observables in ttH sensitive to CP nature of the top Yukawa coupling

Cross-section, Higgs p_T

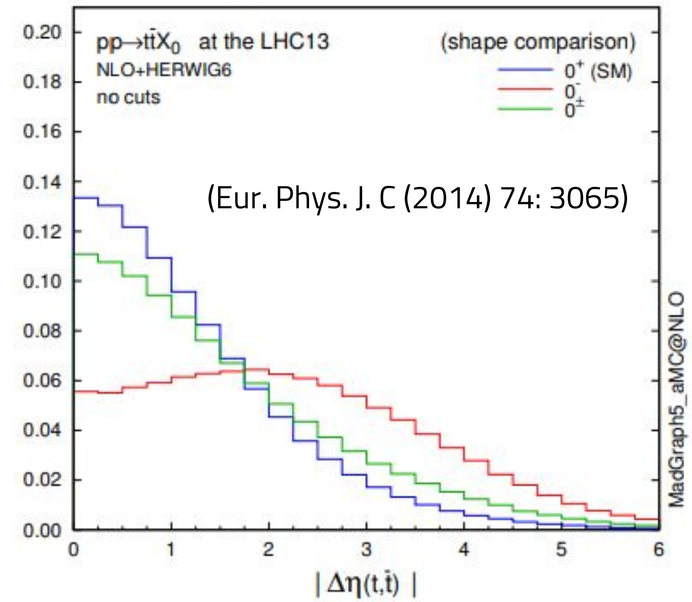
- Cross-section decreases as α deviates from 0
    - Can compensate with coupling strength

- CP-odd component leads to higher fraction of high-p_T Higgs bosons
(Phys. Rev. D 92, 015019, 2015)





Top quark kinematics



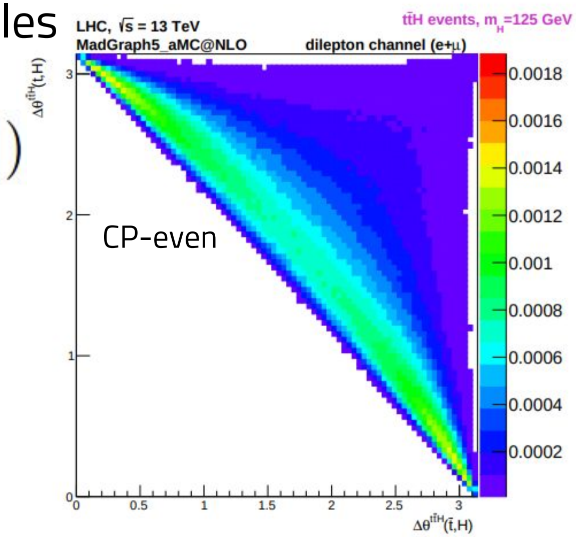
- Top quarks much more separate in η and closer in φ for CP-odd
  (Eur. Phys. J. C (2014) 74: 3065, Phys. Rev. D 92, 015019, 2015)

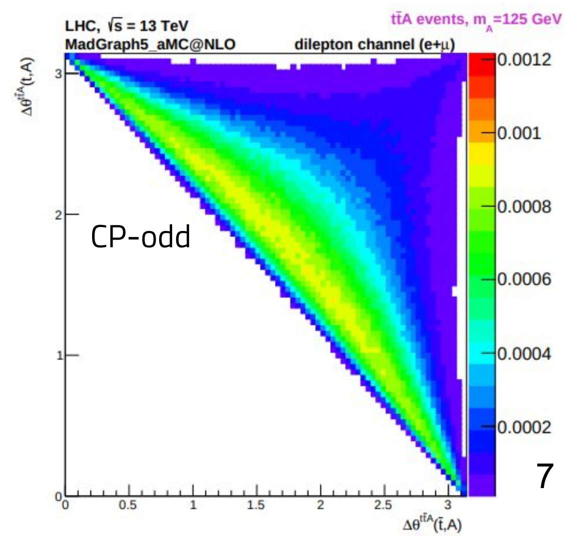
- For CP-even, often one of the top quarks travels close in angle to the Higgs (in ttH frame), while the other nearly opposes it
  (Phys. Rev. D 96, 013004 2017)

- Products of projections of top quark momenta suggested as discriminant observables
  Example:

$$b_4 = (p_t^z . p_{\bar{t}}^z) / (|\vec{p}_t| . |\vec{p}_{\bar{t}}|)$$

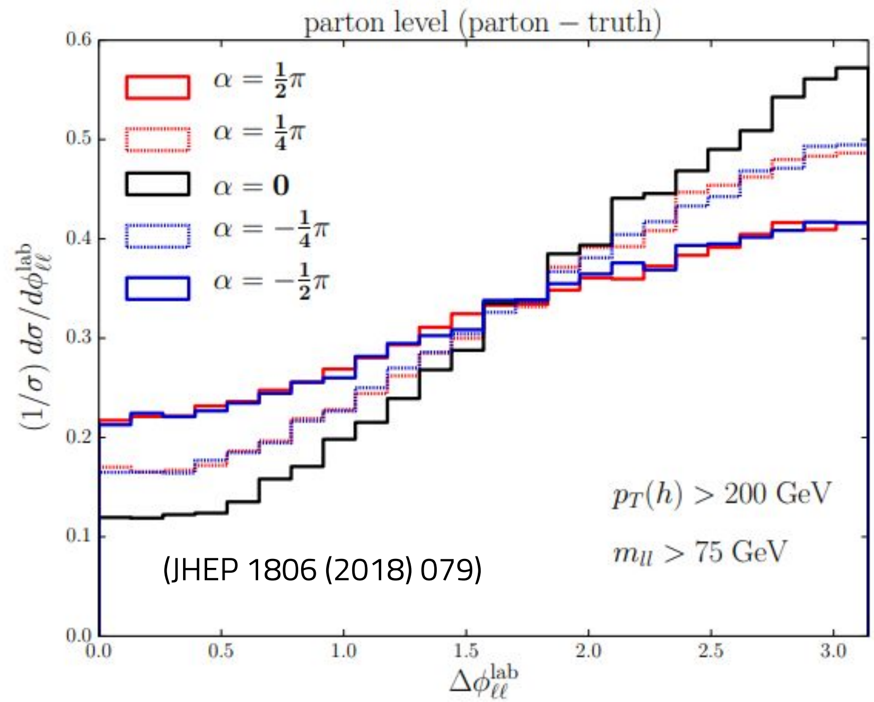
(Phys.Rev.Lett. 76 (1996) 4468-4471)



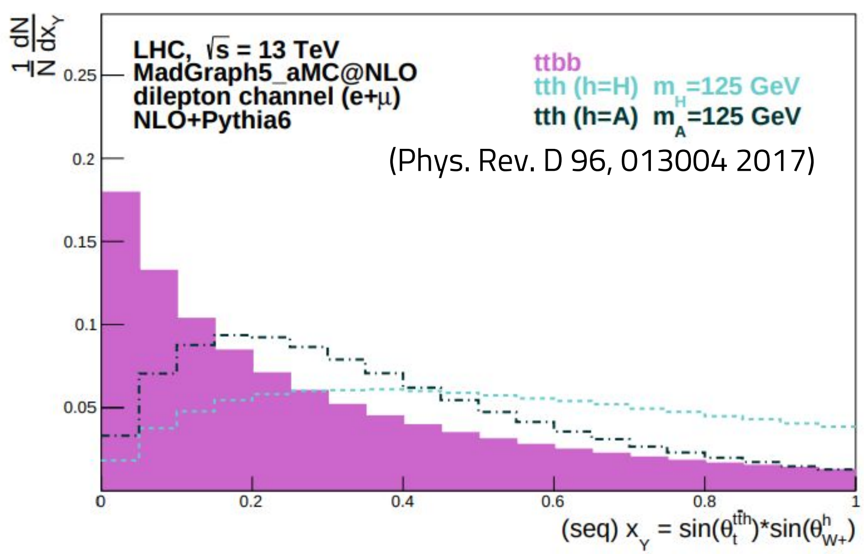


Spin correlations, boosted frames

- tt spin correlations are sensitive to CP-odd component, including sign
  (JHEP 1404 (2014) 004)
- Selecting high-p_T Higgs enhances spin correlations
  (Phys. Rev. Lett. 116, 091801 (2016),
  JHEP 1806 (2018) 079)
- Angles in boosted frames can provide significant discrimination
  (Phys. Rev. D 96, 013004 2017)



(JHEP 1806 (2018) 079)



(Phys. Rev. D 96, 013004 2017)

3.
Sensitivity studies in H⟶bb

Phys. Rev. D 96, 013004 (2017), Phys. Rev. D 98, 033004 (2018)

Event generation, simulation and reconstruction

- ttH and tt+bb generated with aMC@NLO
  - CP-odd and CP-mixed signals using Higgs Characterization NLO (HC_NLO_X0) UFO model
    (JHEP 1311 (2013) 043)
- Other backgrounds generated at LO with merged additional jets
- Fast detector simulation with Delphes
  (JHEP 1402 (2014) 057))

Dilepton

- ≥4 jets and ≥3 b-tags
- Boosted Decision Tree for picking jet assignment. Neutrino solution obtained by imposing m_W and m_t

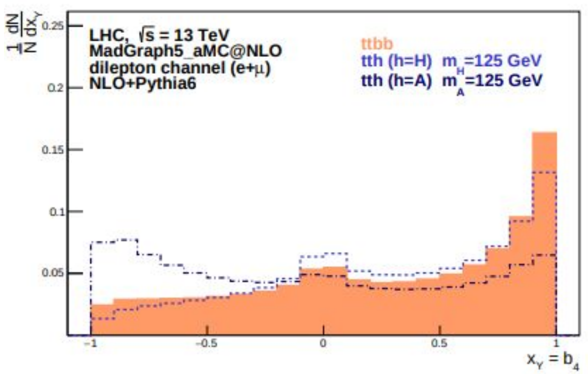
Single lepton

- ≥6 jets and ≥3 b-tags
- KLFitter used for neutrino reconstruction and picking jet assignment
  (Nucl.Instrum.Meth. A748 (2014) 18-25)

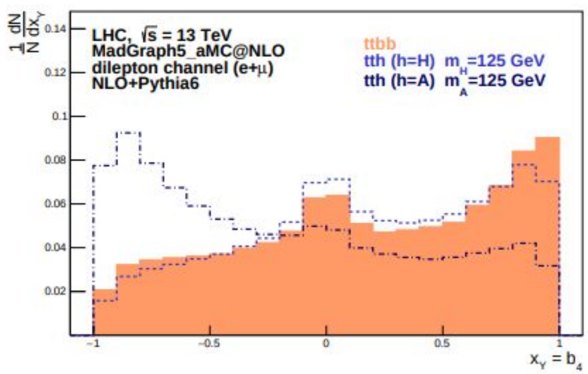
Effect of selection and reconstruction on CP-sensitive observables

- Discrimination is degraded, but not completely lost
- Most degradation happens due to selection cuts, not so much due to reconstruction

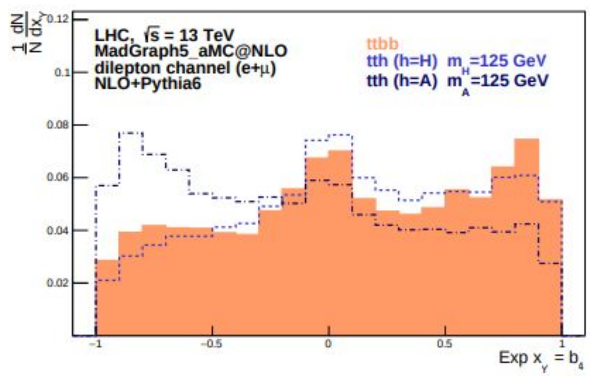
Parton-level



Parton-level after cuts



Reconstruction level

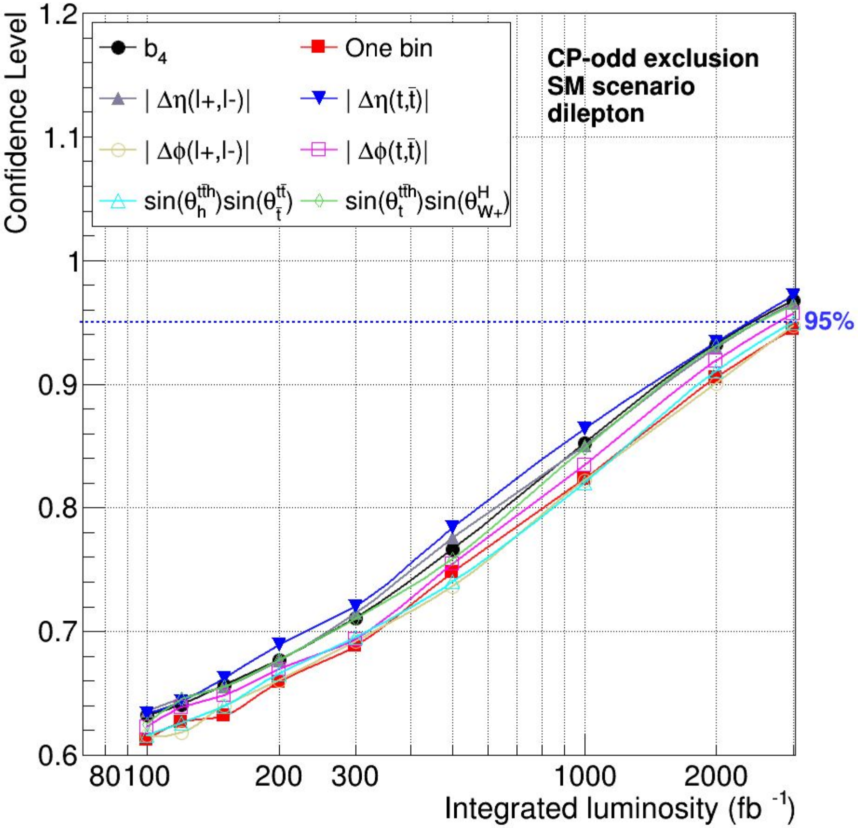


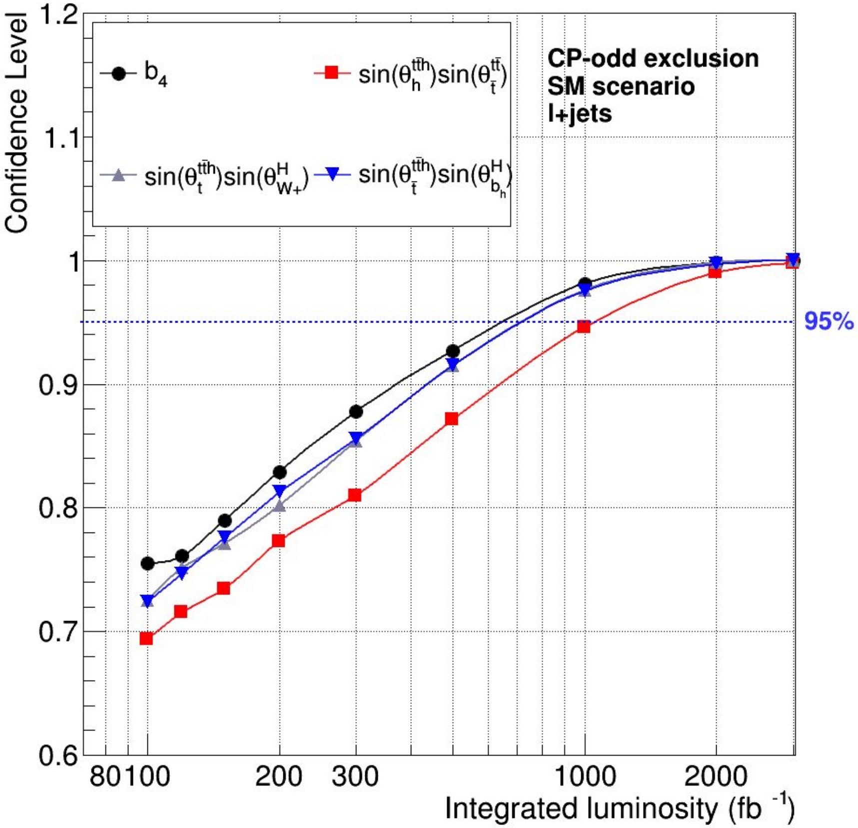
$$b_4 = (p_t^z . p_{\bar{t}}^z)/(|\vec{p}_t| . |\vec{p}_{\bar{t}}|)$$

Expected exclusion confidence level

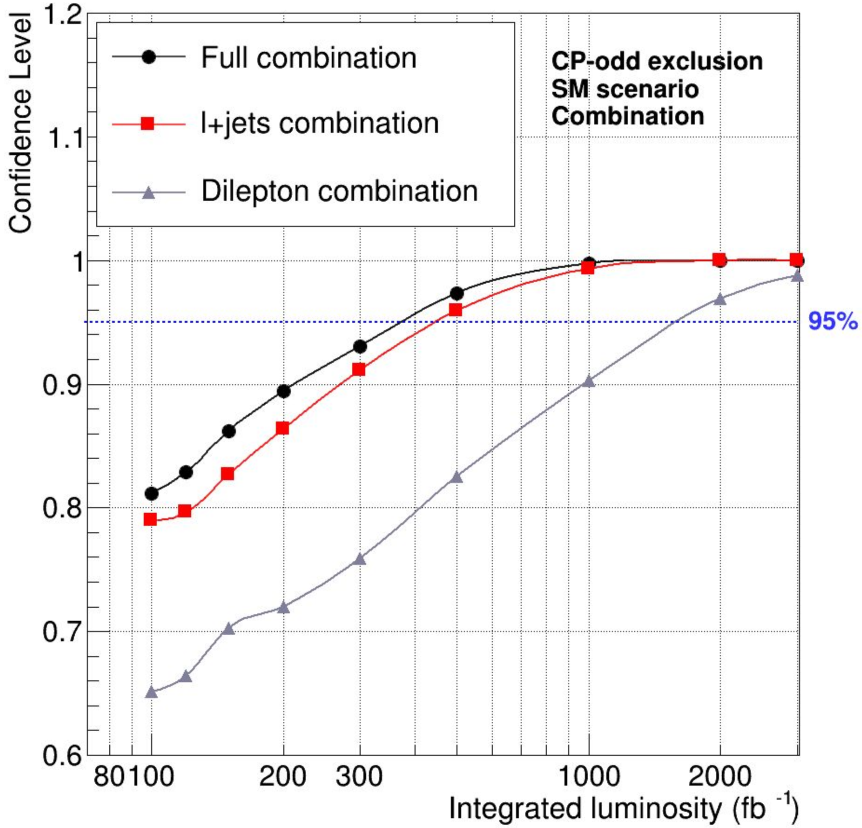
- Exclusion confidence level of pure CP-odd coupling against the SM scenario as function of integrated luminosity
- Words of caution:
  - No further selection to optimize signal region
  - No systematic uncertainties considered
- Assuming BR(H$\rightarrow$bb) as in the SM

Expected exclusion confidence level
- individual observables and channels



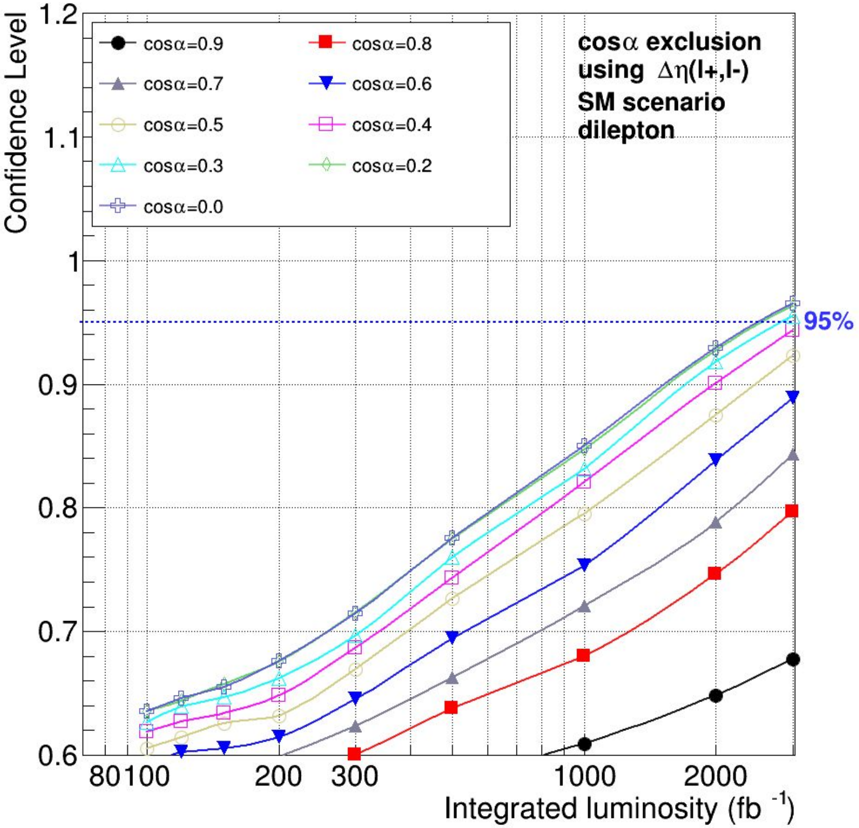


Expected exclusion confidence level - combination



- Combined observables:
  - Single lepton: b_4 and $\sin(\theta^{t\bar{t}h}_{\bar{t}})\sin(\theta^{H}_{b_h})$
  - Dilepton: $\Delta\eta(l^+,l^-)$, $\Delta\varphi(t,t)$ and $\sin(\theta^{t\bar{t}h}_{t})*\sin(\theta^{h}_{W+})$
- Assuming no correlation between variables for Asimov data
- **Pure CP-odd exclusion at 95% CL with ~400 fb^{-1}**

Expected exclusion confidence level - CP-mixed scenarios



- Dilepton only, using $\Delta\eta(l^+,l^-)$ as discriminant distribution
- From cosα=0 to cosα=0.4, only need 25% more luminosity
- From cosα=0 to cosα=0.7 (near maximal mixing) need a factor ~2.5

4.
Summary

Summary

- ttH is the preferred process for precisely measuring the top Yukawa coupling: its magnitude, but also its **structure**
- CP-odd component is theoretically motivated and experimentally accessible through kinematics and spin correlations
- Prospect without systematics: **exclusion of pure CP-odd at 95% with ~400fb^{-1}**, in H→bb alone (single lepton + dilepton, resolved)
  - Exclusion of maximal mixing scenario much more difficult, may be only within reach with ~1ab^{-1}
- Combination with boosted topologies and other channels besides H→bb would give a more optimistic prospect

Thanks!

Event generation and simulation

- ttH and tt+bb generated with aMC@NLO
  (arXiv:1405.0301)
  - CP-odd and CP-mixed signals using HC_NLO_X0 UFO model
    (JHEP11(2013)043)
- Other backgrounds generated with MadGraph5 @LO with additional jets
- Decay of heavy resonances with MadSpin
  (arXiv:1212.3460)
- Parton shower and hadronisation with Pythia6
  (JHEP 0605:026,2006)
- Fast detector simulation with Delphes, using included “ATLAS” parameter card
  (JHEP 2014: 57)

Analysis and reconstruction strategies

- Leptons and jets selected with p_T>20 GeV and $|\eta|$<2.5

Dilepton

2 opposite-sign leptons
≥4 jets and ≥3 b-tags

Boosted Decision Tree for picking jet assignment

Neutrino solution by imposing W and top masses

Single lepton

1 lepton
≥6 jets and ≥3 b-tags
Missing E_T>20 GeV

Reconstruction done with KLFitter, which also picks the best jet assignment
(arXiv:1312.5595)