Top-Higgs couplings at high energies

— CPV in ttH and tHj processes —

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Based on: JHEP 1404 (2014) 004 (arXiv:1312.5736)

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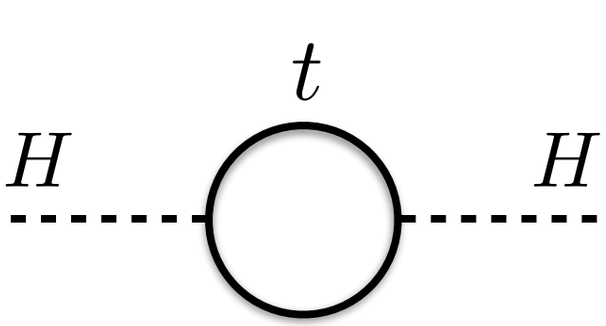
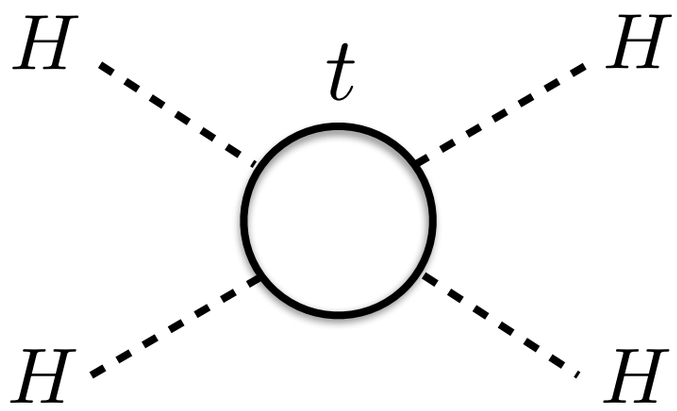
Introduction

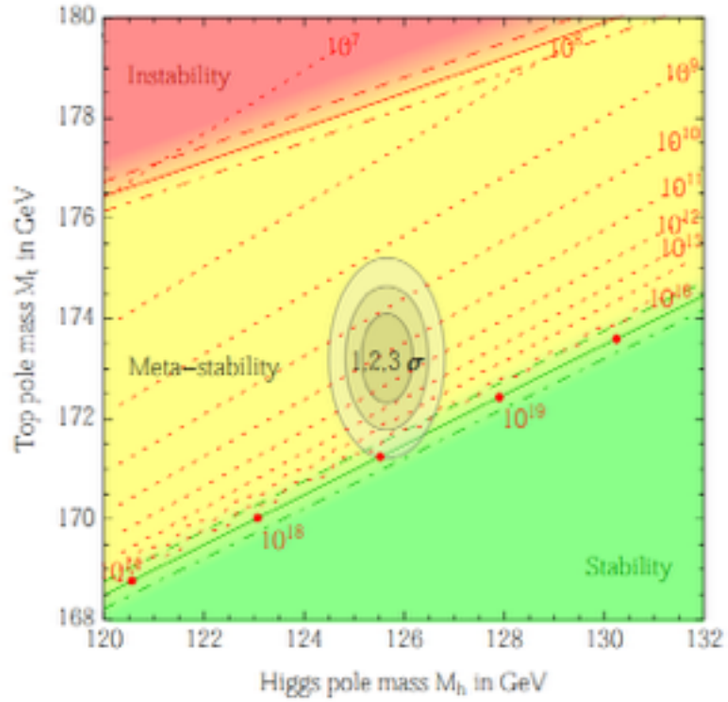
- A Higgs-like particle has been discovered. The property of it (mass, coupling, CP) has began to be measured.

- Top-Higgs coupling is important because it is:

  - the largest coupling in the SM
  - closely related to the gauge hierarchy problem
  - closely related to the stability of the Higgs potential
  - ...







Dario Buttazzo, et.al. (1307.3536)

Anomalous top-Higgs coupling

- We parametrise the top-Higgs coupling as:

$$\mathcal{L}_t = -\frac{m_t}{v}\left(\kappa_t \bar{t}t + i\tilde{\kappa}_t \bar{t}\gamma_5 t\right)H \qquad \text{SM: } (\kappa_t, \tilde{\kappa}_t) = (1, 0)$$

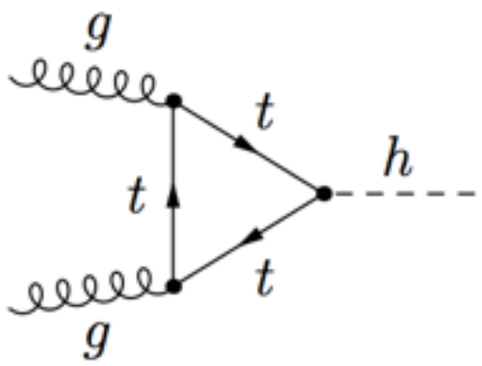
CPV

- The top-Higgs coupling enters the Higgs production and decay:

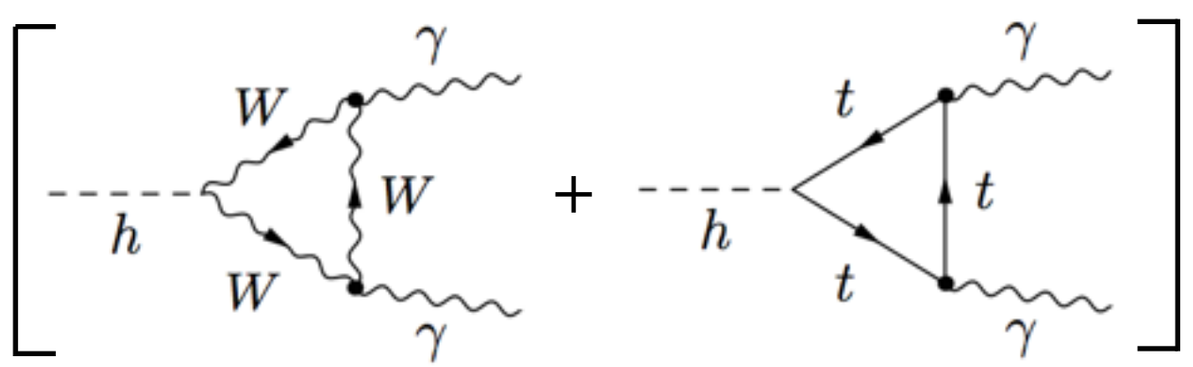
$$\mathcal{L}_\Delta = -\left[\frac{\alpha_s}{8\pi} c_g b_g G^a_{\mu\nu} G^{\mu\nu a} + \frac{\alpha_{em}}{8\pi} c_\gamma b_\gamma F_{\mu\nu} F^{\mu\nu}\right]\left(\frac{H}{v}\right)$$

SM: $(c_g, c_\gamma) = (1, 1)$

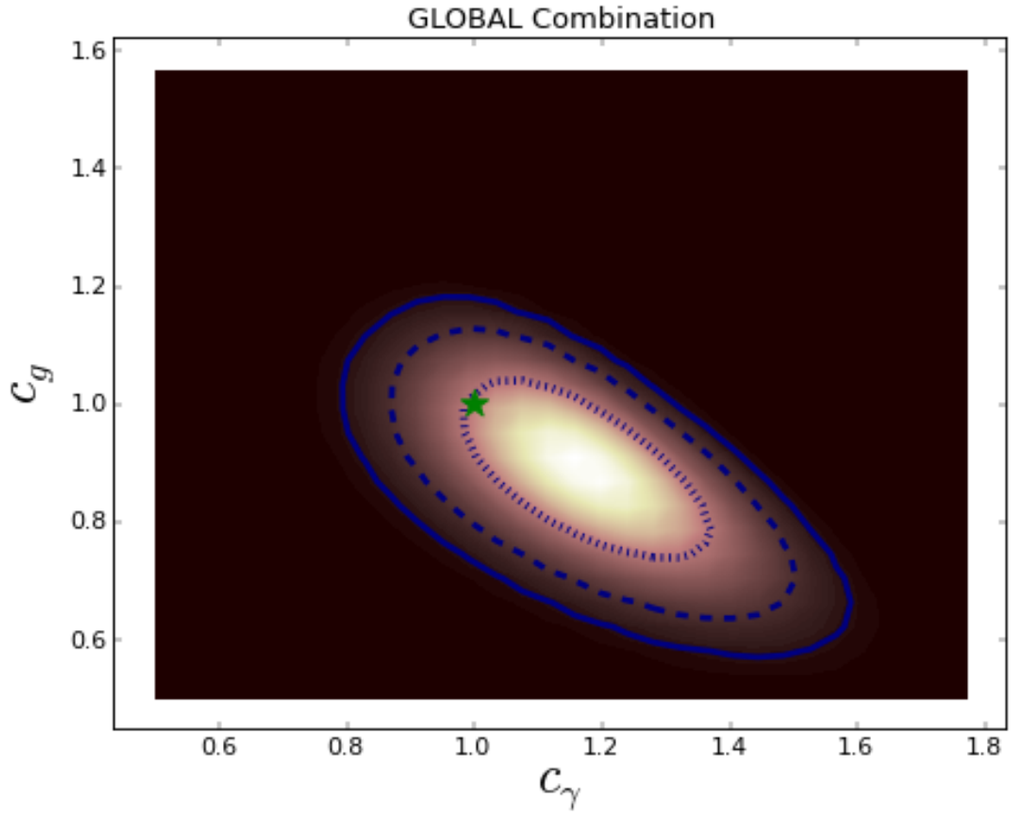
Production



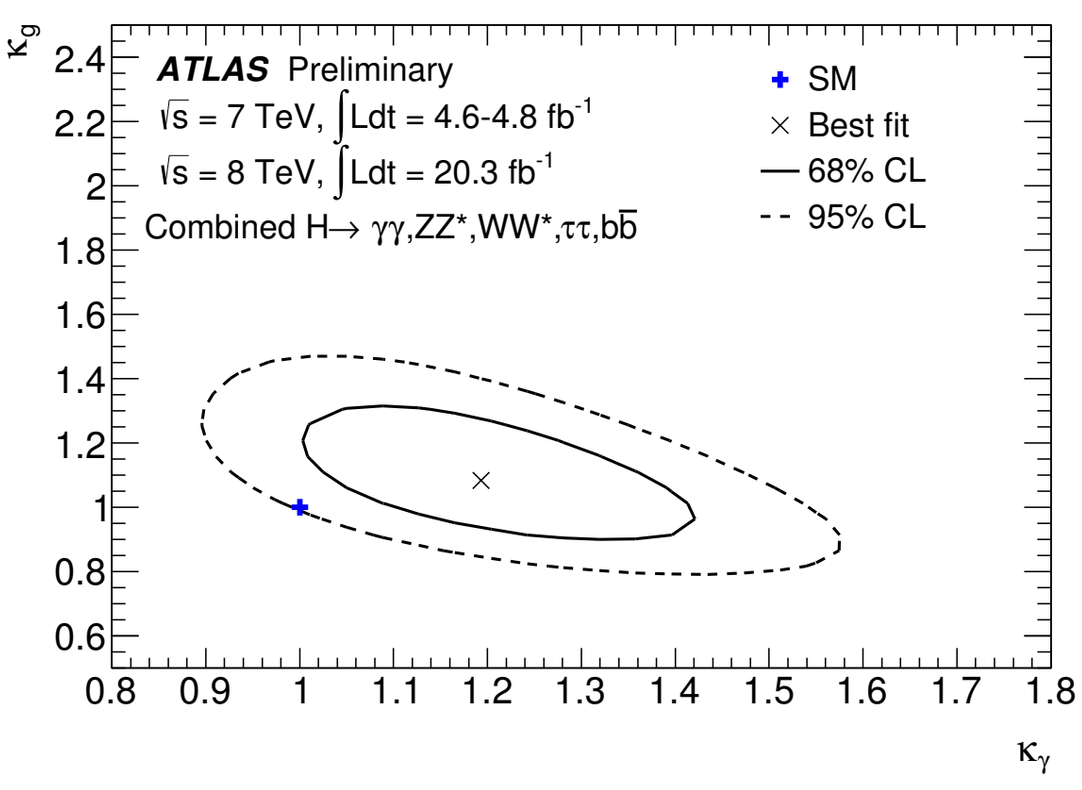
Decay

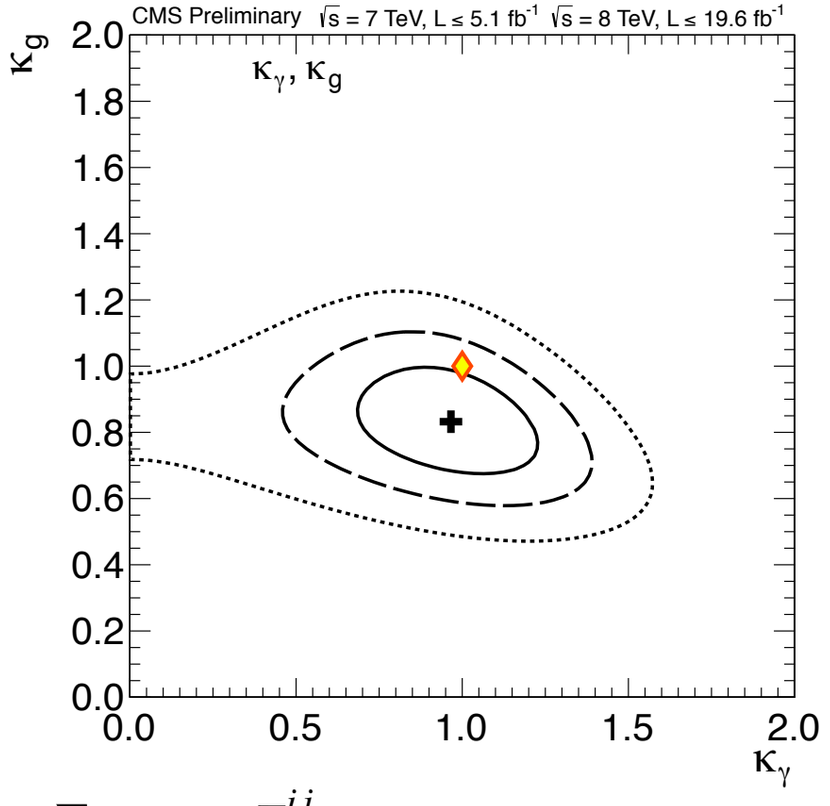


John Ellis, Tevong You (1303.3879)



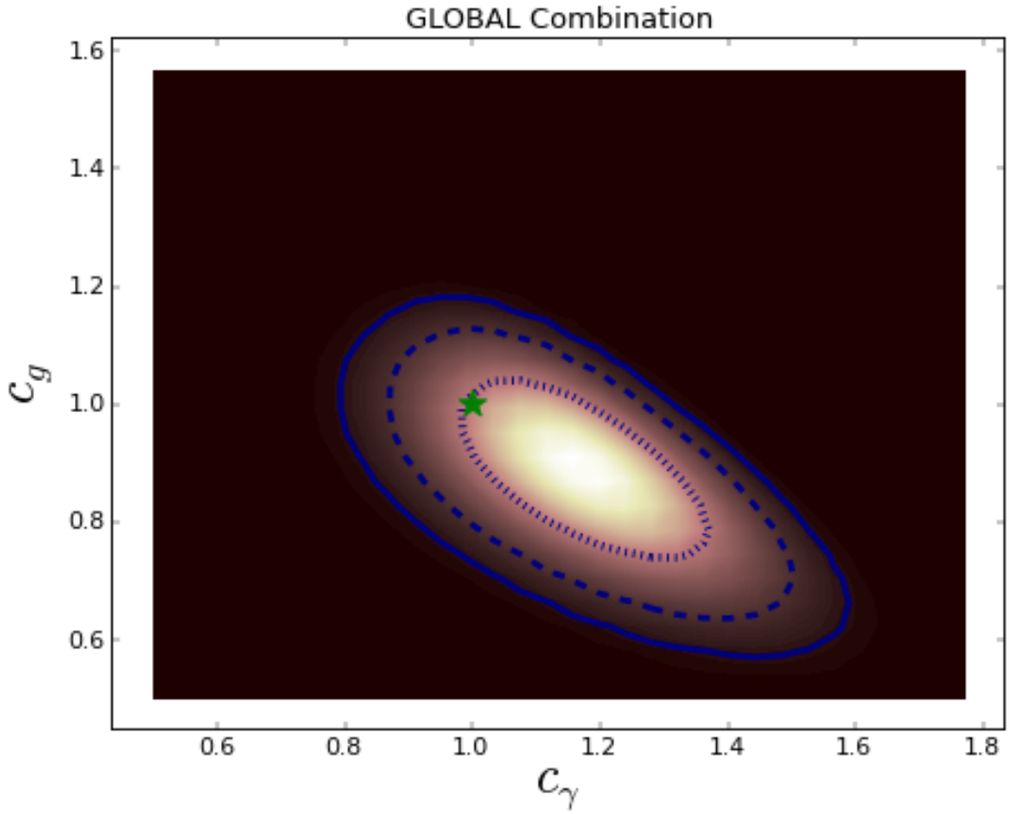
Constrains on ggH and γγH couplings



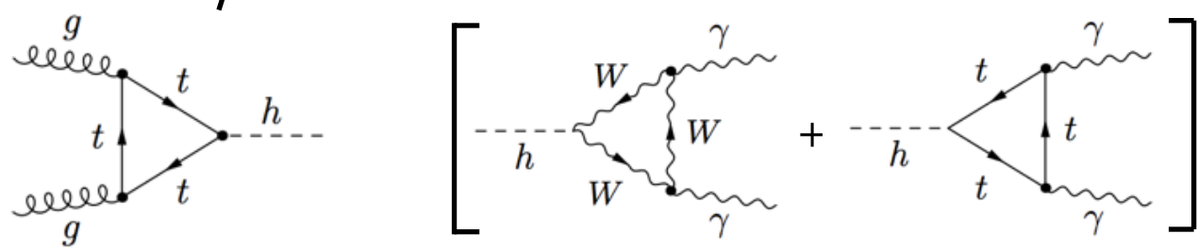


$$\kappa_g^2(\kappa_b,\kappa_t) = \frac{\kappa_t^2\cdot\sigma_{ggH}^{tt}+\kappa_b^2\cdot\sigma_{ggH}^{bb}+\kappa_t\kappa_b\cdot\sigma_{ggH}^{tb}}{\sigma_{ggH}^{tt}+\sigma_{ggH}^{bb}+\sigma_{ggH}^{tb}} \qquad \kappa_\gamma^2(\kappa_b,\kappa_t,\kappa_\tau,\kappa_W) = \frac{\sum_{i,j}\kappa_i\kappa_j\cdot\Gamma_{\gamma\gamma}^{ij}}{\sum_{i,j}\Gamma_{\gamma\gamma}^{ij}}$$

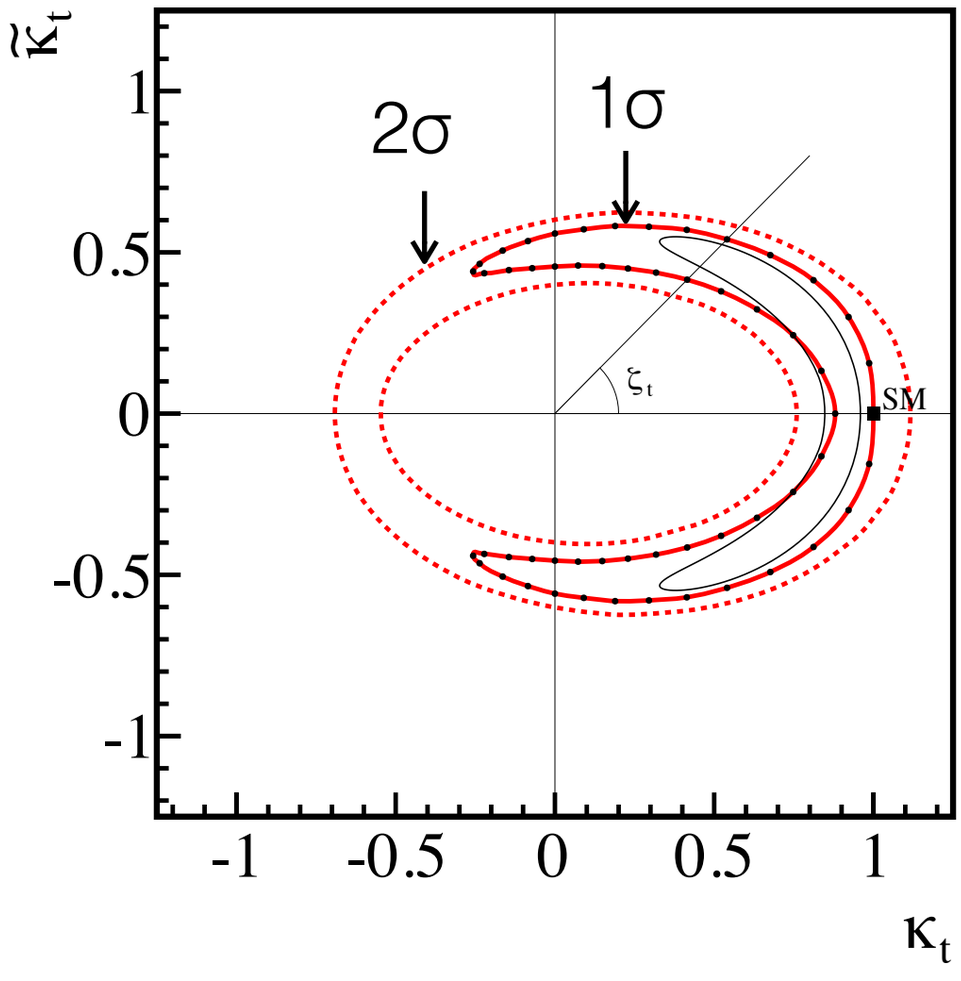
John Ellis, Tevong You (1303.3879)



$$\mathcal{L}_\Delta = -\left[\frac{\alpha_s}{8\pi} c_g b_g G^a_{\mu\nu} G^{\mu\nu a} + \frac{\alpha_{em}}{8\pi} c_\gamma b_\gamma F_{\mu\nu} F^{\mu\nu}\right]\left(\frac{H}{v}\right)$$



$$\mathcal{L}_t = -\frac{m_t}{v}(\kappa_t \bar{t}t + i\tilde{\kappa}_t \bar{t}\gamma_5 t)H$$



- The CPV phase ζ_t is largely arrowed.
- Du to the interference in c_γ, the constraints for $\kappa_t > 0$ and < 0 are not symmetric. $\zeta_t = \pi$ is excluded at 1σ.
- For 2σ, ζ_t is not constrained at all.
- The ζ_t can be constrained by the EDMs, though they are model dependent (J.Brod, U.Haisch, J.Zupan, 2013).

ttH and tHj

- If the anomalous top-Higgs couplings exist, the effect should be seen in $pp \to \bar{t}tH$ and $pp \to tHj\,(\bar{t}Hj)$.

- Challenging processes. Cross sections are small: σ(ttH) ~ 130 fb, σ(tHj) ~ 18 fb at 8 TeV LHC.

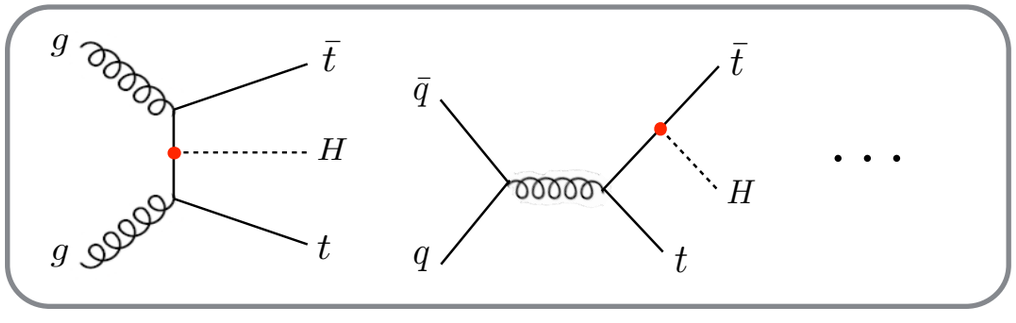
- No signal has been observed.

$$\begin{cases} \sigma(t\bar{t}H) < 4-5 \times \sigma(t\bar{t}H)_{\rm SM} \longrightarrow \text{next two talks} \\ \text{No limit for } tHj \end{cases}$$

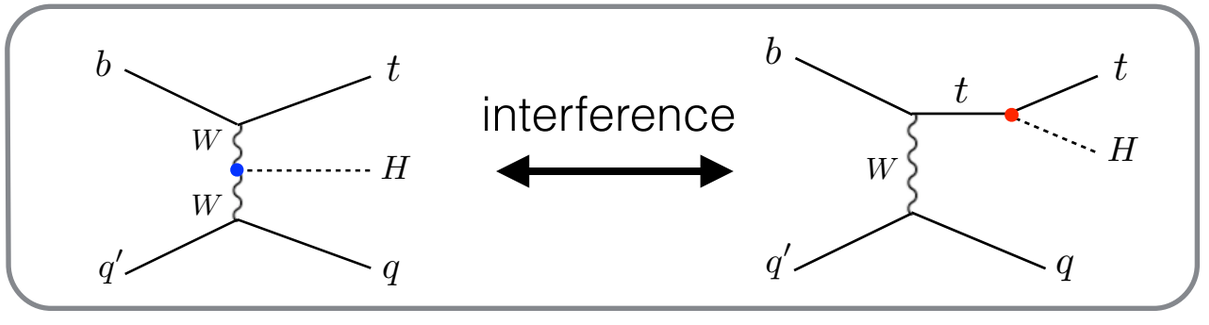
Cross Section

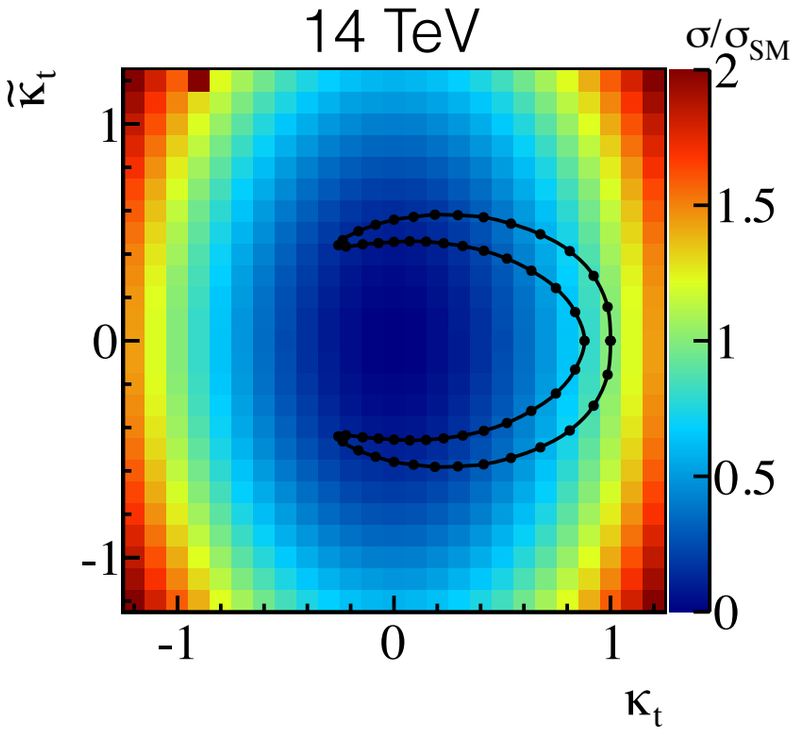
- How are the cross sections affected by the anomalous top-Higgs coupling?

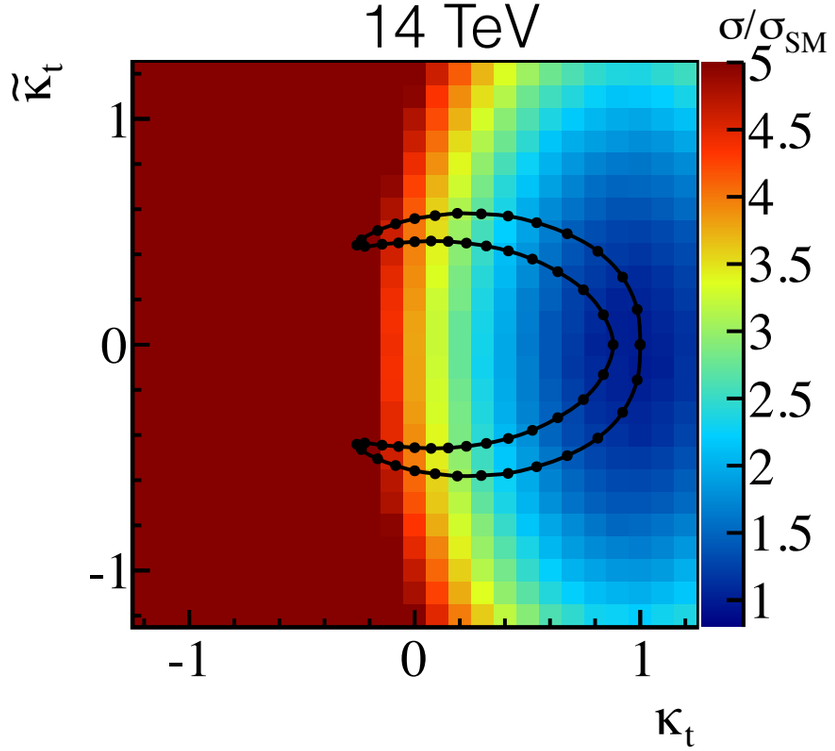
$pp \to \bar{t}tH$



$pp \to tHj\,(\bar{t}Hj)$







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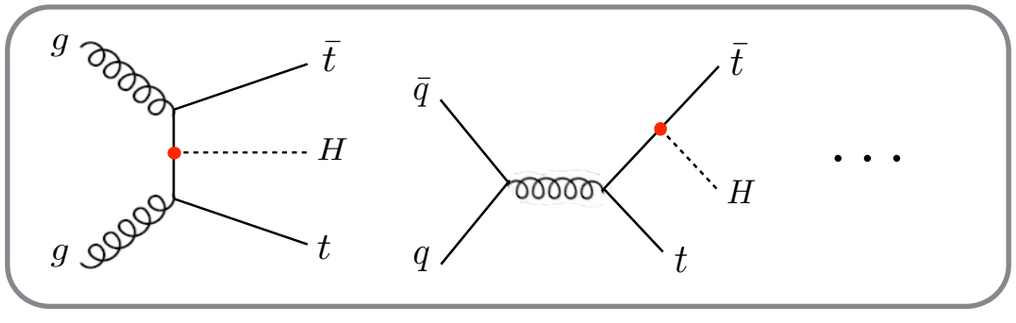

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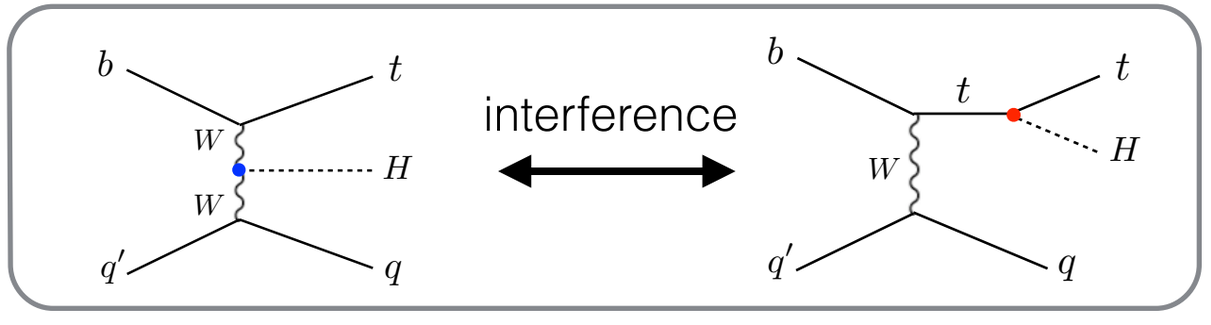
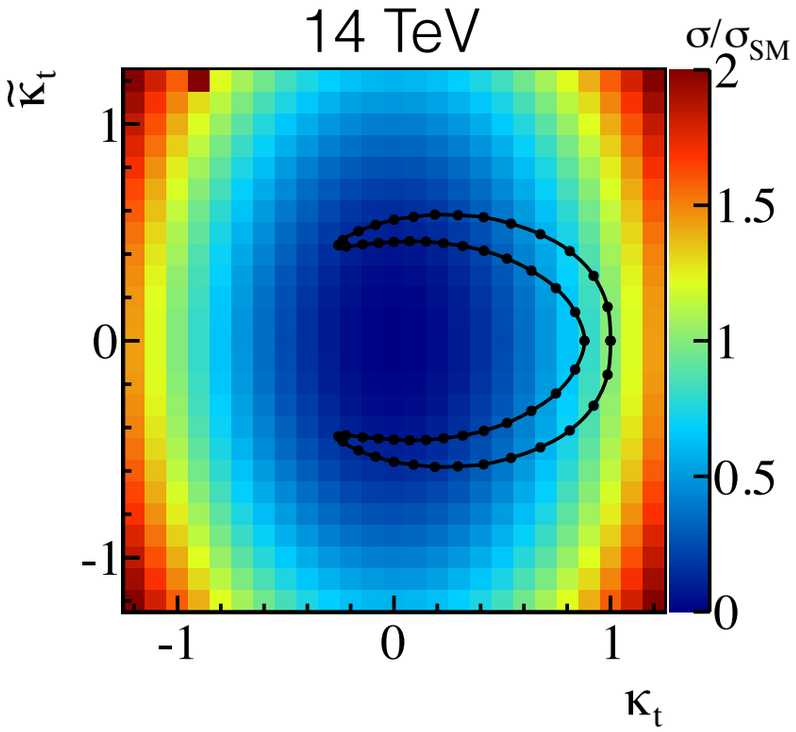
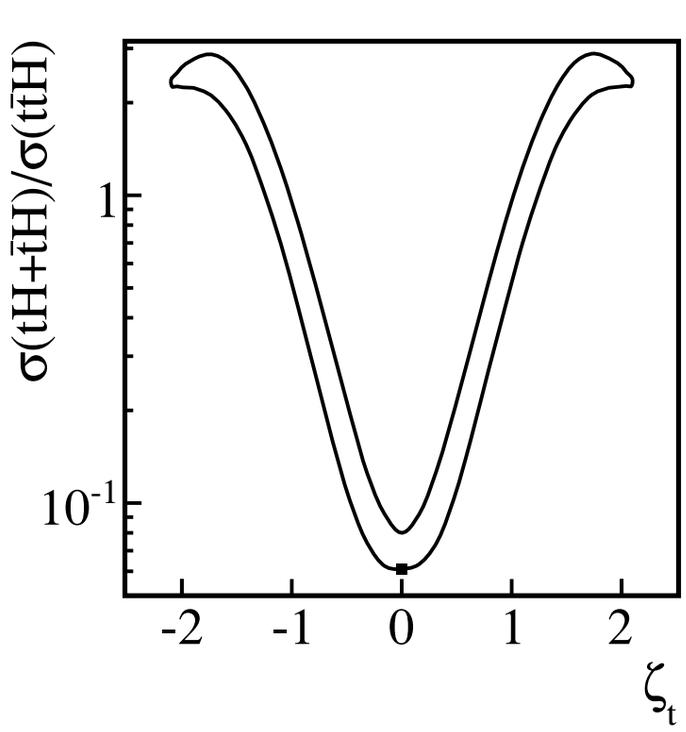
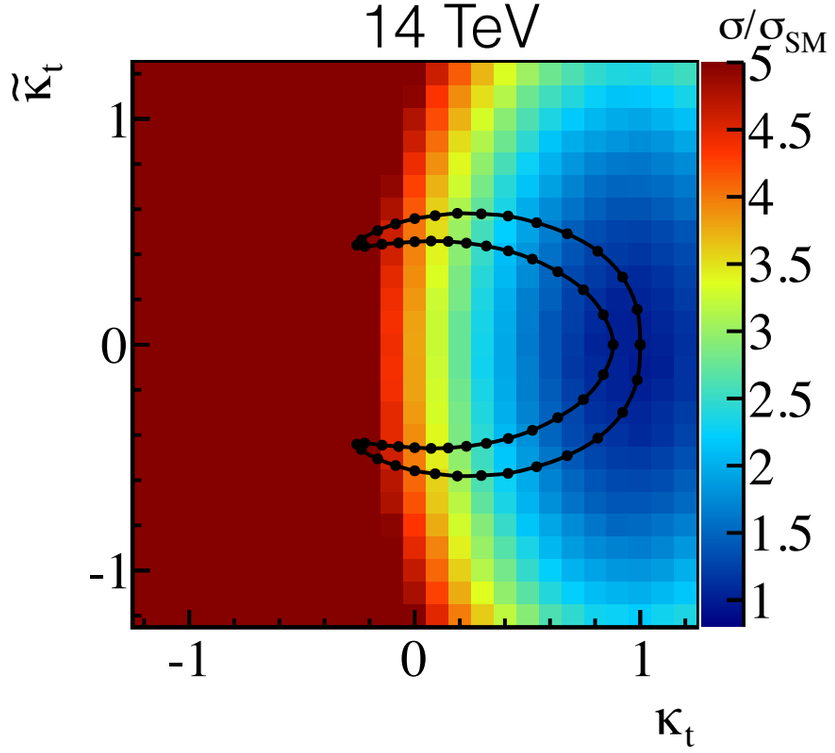


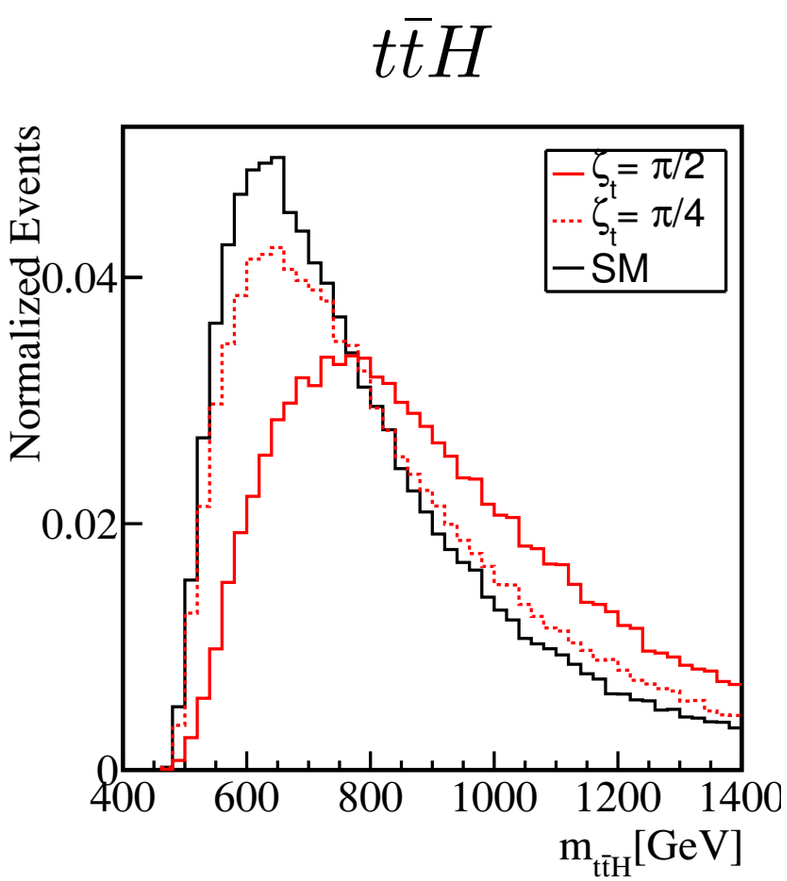


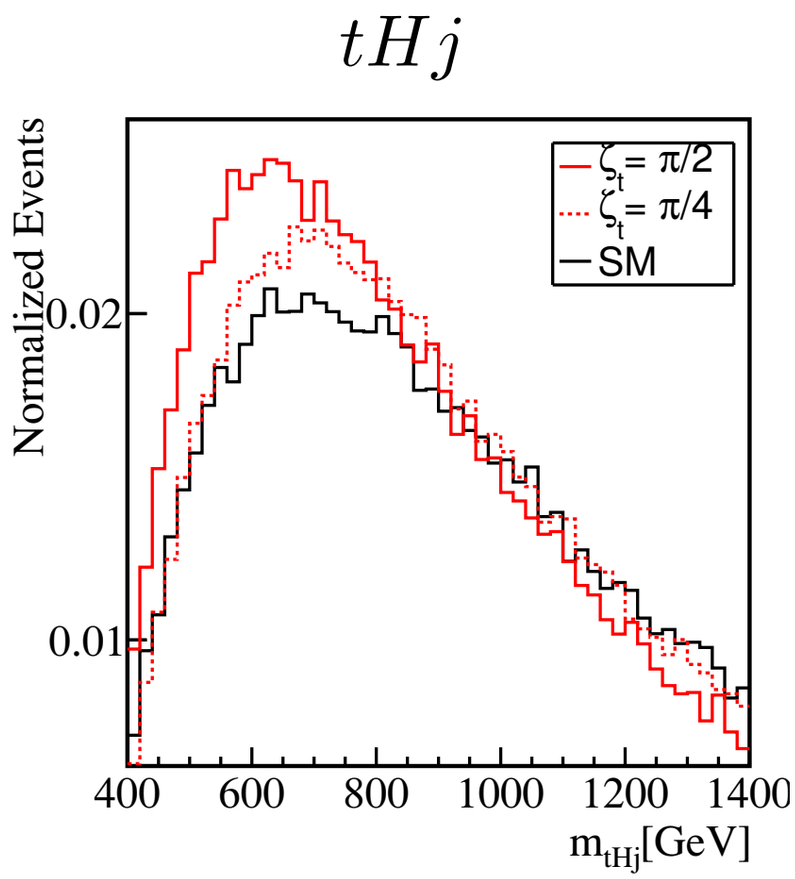


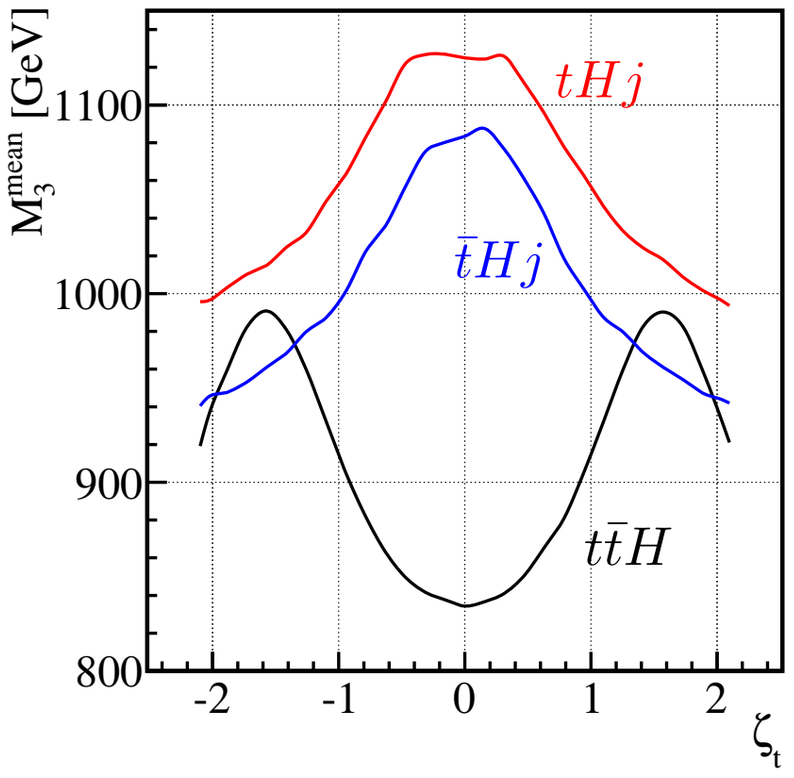


- For $\zeta_t > 1.2$, $\sigma(tHj)$ can become larger than $\sigma(ttH)$.
- The difference from the SM is a factor of 20 at the maximum.

Invariant Mass





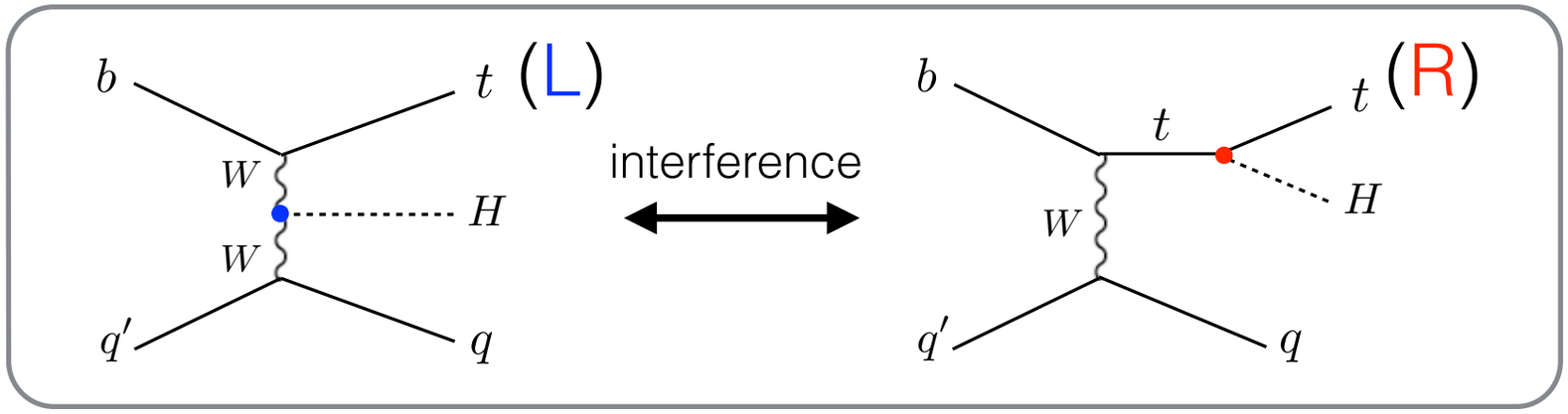


- For ttH, the total invariant mass increases as increasing the CP phase ζ_t.
- For tHj, the total invariant mass decreases as increasing ζ_t.

14 TeV, Parton Level

Spin measurement in tHj

- In the diagram without ttH coupling the top is dominantly left-handed, whereas it is right-handed in the diagram with ttH. Modification of ttH coupling may affect the top polarisation measurement in tHj.

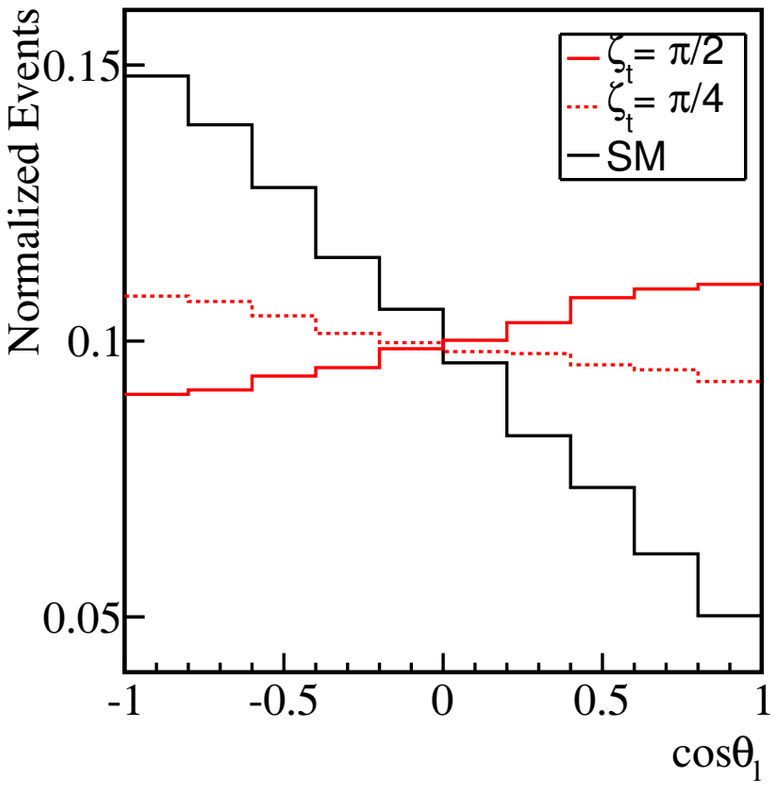


- The top polarisation can be measured by the angle of the lepton w.r.t the top boost direction at the top rest frame.

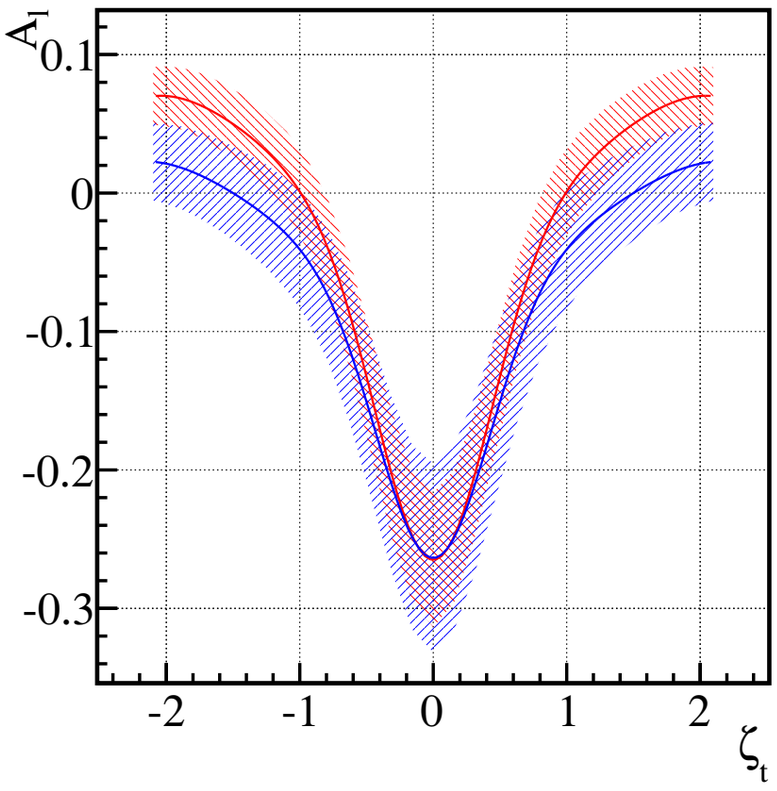
$$\frac{1}{\Gamma_\ell}\frac{d\Gamma_\ell}{d\cos\theta_\ell} = \frac{1}{2}(1 + P_t \cos\theta_\ell)$$

$P_t = \pm 1$ for pure right(left)-handed top

Spin measurement in tHj



- The $\cos\theta_l$ distribution but in the tHj rest frame
- Some dependency of the CP phase
- In SM the lepton prefers the opposite direction to the top boost direction, whereas for $\zeta_t = \pi/2$, it prefers the same direction.



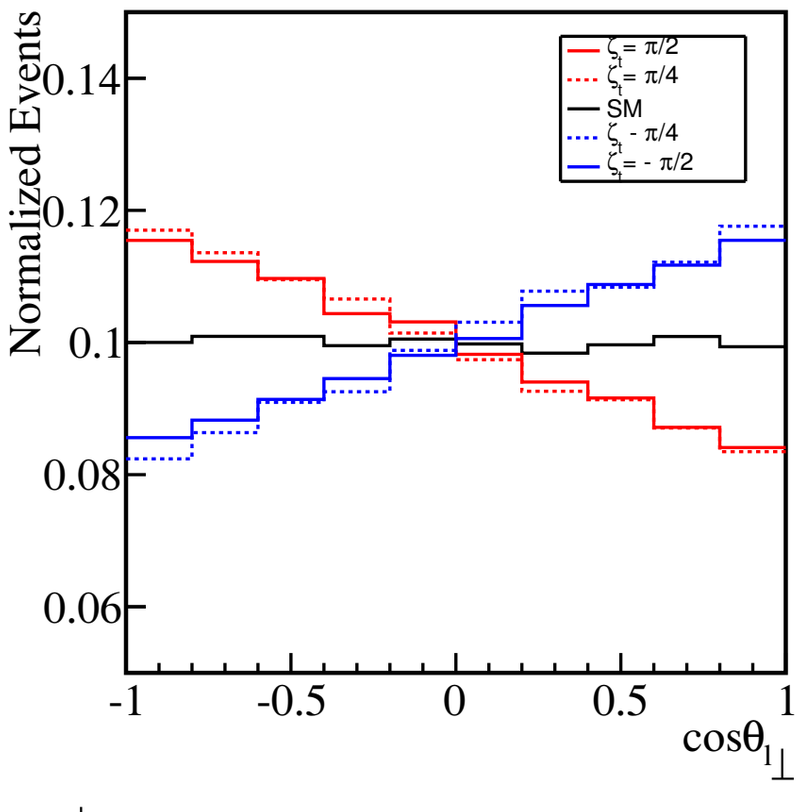
- The asymmetry is an useful measure.

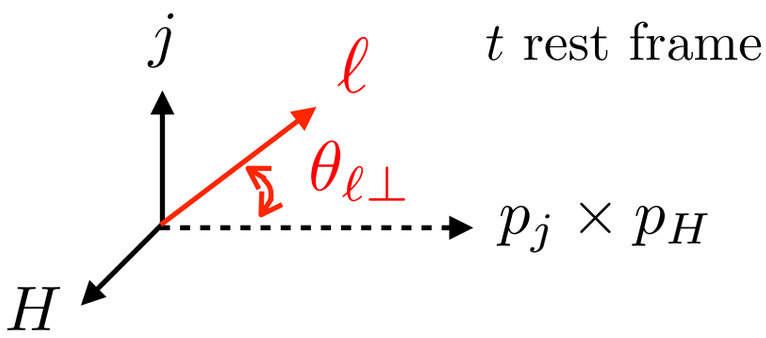
$$A_\ell = \frac{N(\cos\theta_\ell > 0) - N(\cos\theta_\ell < 0)}{N(\cos\theta_\ell > 0) + N(\cos\theta_\ell < 0)}$$

- tHj and tbarHj. The band is the statistic error assuming 14 TeV LHC with 100 fb^{-1}.
- $\zeta_t > 0$ and < 0 are not distinguishable.

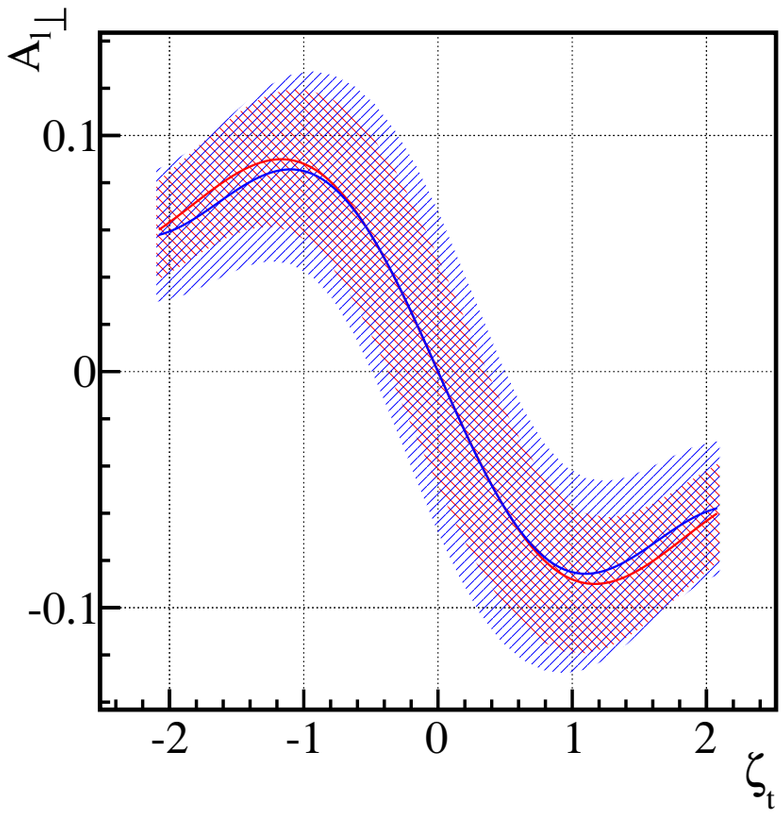
14 TeV, Parton Level

The angle from prod. plane





- The SM has a flat distribution => no CPV
- With $\zeta_t \neq 0$, the lepton prefers a particular direction depending on the sign of ζ_t.

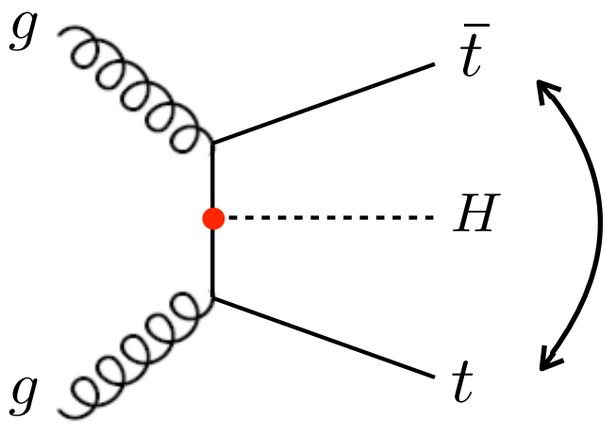


$$A_\ell = \frac{N(\cos\theta_\ell > 0) - N(\cos\theta_\ell < 0)}{N(\cos\theta_\ell > 0) + N(\cos\theta_\ell < 0)}$$

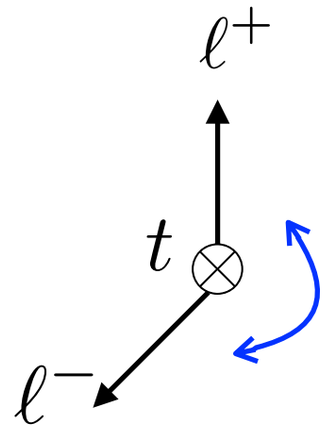
- $\zeta_t > 0$ and < 0 are distinguishable.

14 TeV, Parton Level

Spin Correlation in ttH

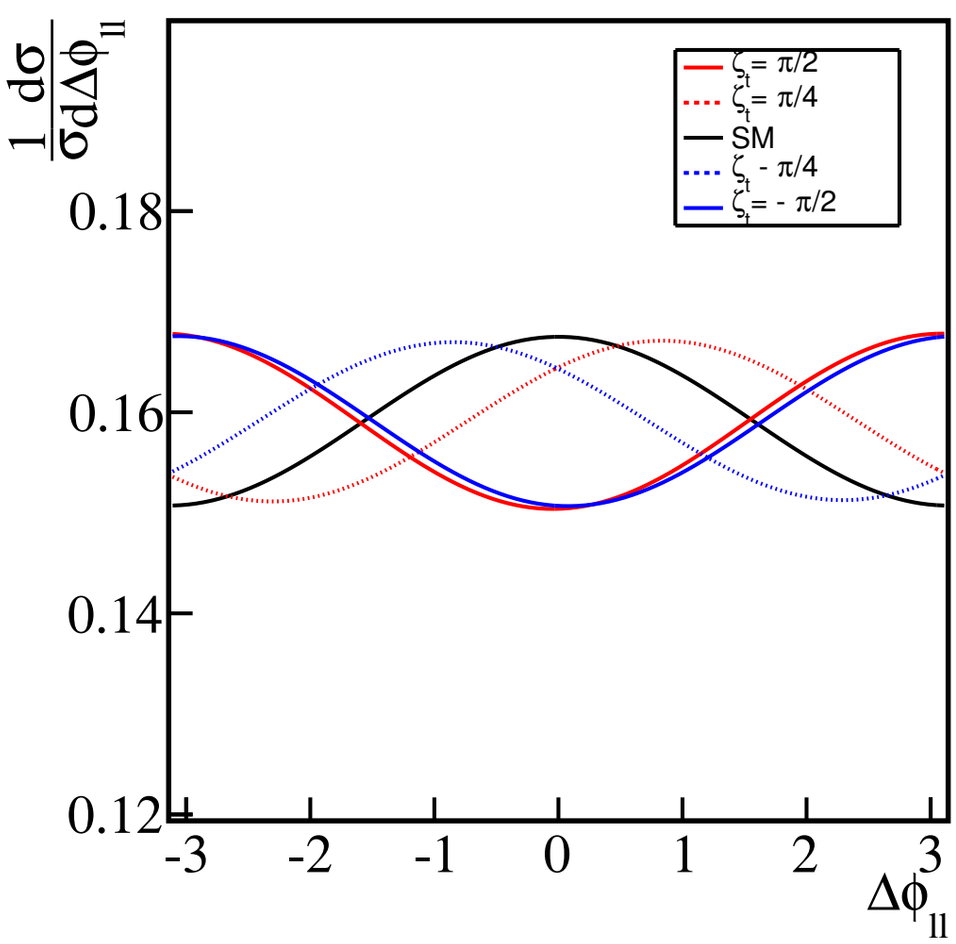


spin correlation
among the tops



$\bar{t}t$ rest frame

The sign is defined by the direction of the top.
This is important to capture the CP violation.



- $\Delta\phi_{\ell\ell}$ can discriminate $\xi_t > 0$ and < 0.
- The fit shows:

$$\frac{d\sigma}{d\Delta\phi_{\ell\ell}} \propto \cos(\Delta\phi_{\ell\ell} - \delta) + \text{const}$$

$$\delta = 2\xi_t - \sin(2\xi_t)/2$$

14 TeV, Parton Level

Conclusion

- The top-Higgs coupling is constrained by various measurements of the Higgs production and decay, but a lot of room is left by allowing the CPV coupling.
- The anomalous top-Higgs coupling should be directly measured in the ttH and tHj, though the measurements may be challenging.
- The ratio of the production cross sections of ttH and tHj is very sensitive to the modification of the top-Higgs coupling in the SM.
- The lepton angle from the production plane of tHj and the angular correlation in the ttH are good variable to measure the CPV in the top-Higgs coupling.
- The analysis is parton level. Dedicated studies including detector effect is necessary.

14 TeV, Parton Level