Directly Probing the Higgs-top Coupling at High Scales

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Why

Motivation

Top Yukawa, y_t

- (y_t), at ~ 1, is the **strongest** interaction of the Higgs boson in SM and hence most **sensitive** to BSM physics.
- It is crucial to the stability of SM vacuum during EWSB; has the dominant contribution to quantum corrections to Higgs mass etc.
- Precise measurement of y_t can be fundamental to pin down possible NP.
- HL-LHC projects measurement of y_t to an accuracy of $\delta y_t \leq \mathcal{O}(4)\%$.

Probing at High Scales

- Current measurements are at EW scale, Q $\sim$ v.
- BSM effects scale as $\left(\frac{Q}{\Lambda}\right)^{n>0}$; $\Lambda =$ NP scale.
- **NP effects can be enhanced by exploring top Yukawa at high scales.**

How

Direct probe of top Yukawa at high scales

- Recently some proposals were made to study off-shell Higgs in the $gg \to h^* \to VV$ channel to probe Higgs physics at high scales (see previous talk by Han Qin, and tomorrow's by Tao Han)[2].
- In this work we **directly** probe Higgs-top coupling at **high scales** using **on-shell Higgs production with high** $p_{T,h}$.
- We look at the $pp \to t\bar{t}h$ channel, where at high scales we can simultaneously enhance NP effects and suppress backgrounds.
- The new physics sensitivity is parametrized in terms of the effective field theory framework, and a non-local Higgs-top coupling form-factor.

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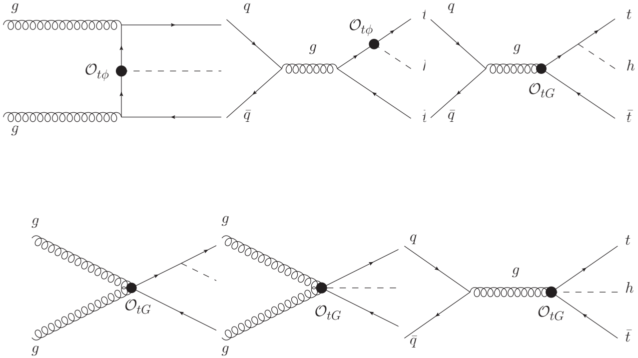
[2] Gonçalves, Han, Mukhopadhyay (2018)
Gonçalves, Han, Leung, Qin (2020)

EFT framework

- EFT is usually parameterized as, $\mathcal{L}_{\mathrm{EFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i + \mathcal{O}\left(\frac{1}{\Lambda^4}\right)$
- Focusing on 2 fermion operators, we study the following operators.
  - $\mathcal{O}_{t\phi} = (H^\dagger H)(\bar{Q}t)\tilde{H} + \mathrm{h.c.}$
    which simply **rescales the SM top Yukawa coupling**, and
  - $\mathcal{O}_{tG} = ig_s(\bar{Q}\tau^{\mu\nu}T_A t)\tilde{H}G^A_{\mu\nu} + \mathrm{h.c.}$
    the **chromo-dipole moment of top quark**. It modifies gtt vertex and introduces new vertices $ggtt, gtth, ggtth$.



Higgs-top coupling form-factor

- The top-quark Yukawa coupling has a special role in the naturalness problem, displaying the dominant quantum corrections to the Higgs mass.
- Many well motivated scenarios consider the **top quark and Higgs as composite particles** arising from strongly interacting new dynamics at a scale Λ. [3]
- In such scenarios, **top Yukawa has momentum-dependent form-factor rather than a point-like interaction**.
- Motivated by nucleon form-factor we adopt the ansatz. $\Gamma(Q^2/\Lambda^2) = \frac{1}{(1+Q^2/\Lambda^2)^n}$, with n=2 the dipole form-factor (corresponding to exponential spatial distribution).

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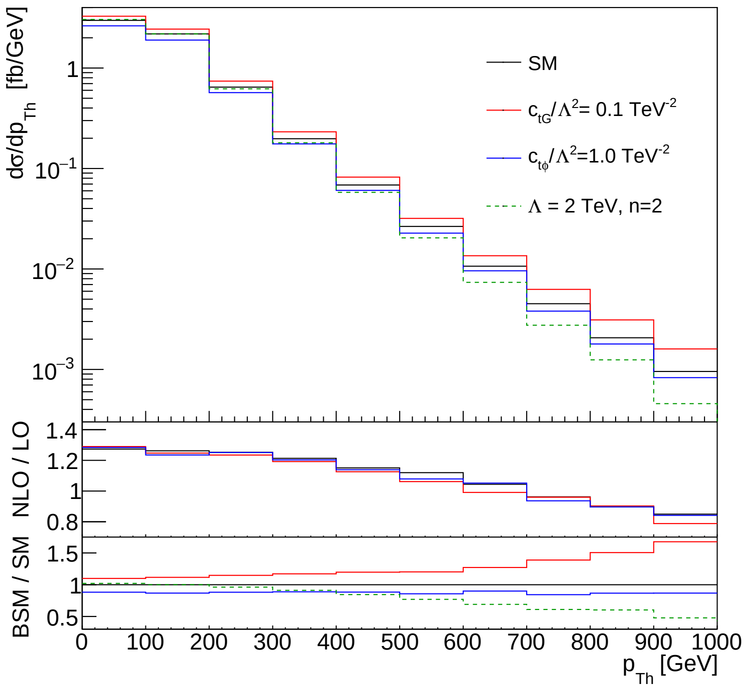
[3] Pomarol, Riva (2012); Panico, Wulzer (2015); Liu, Low, Wagner (2017) etc.

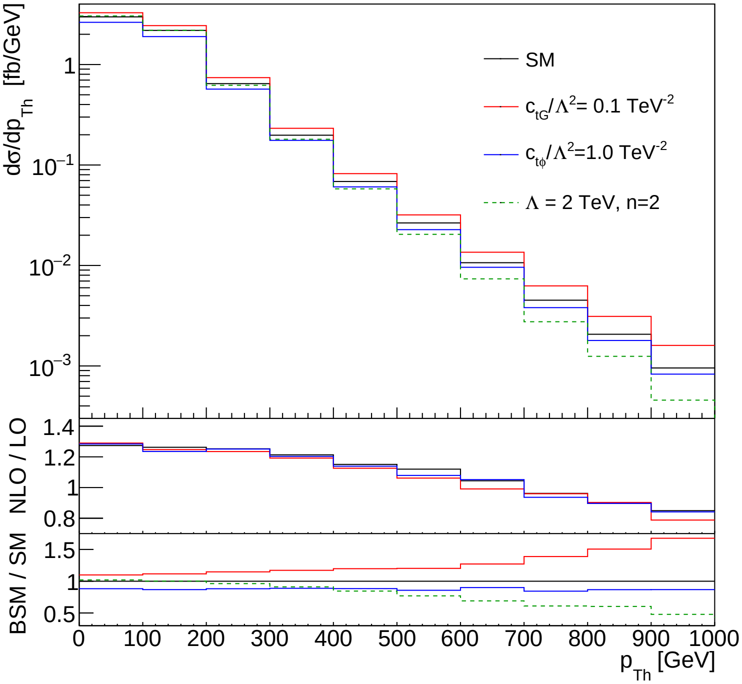
New Physics Effects

Higher order and BSM effects



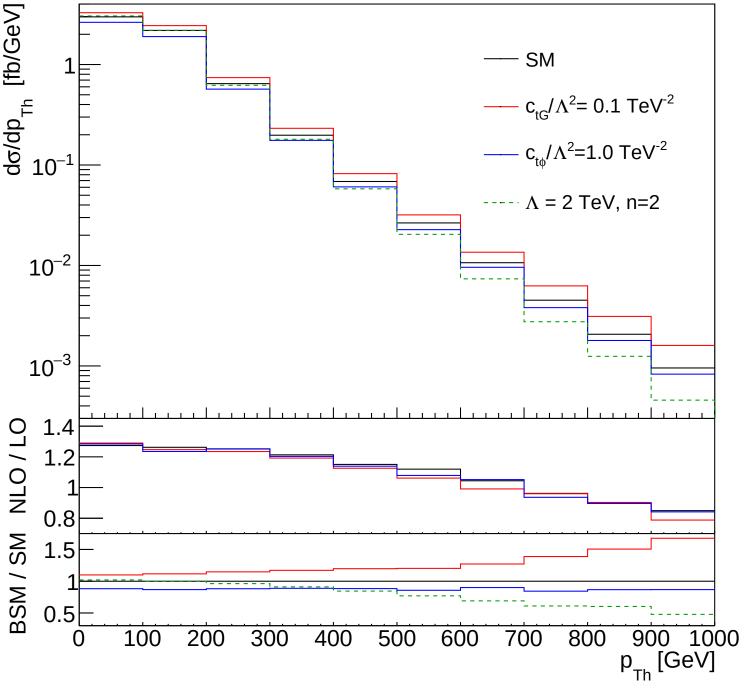
- The K-factor decreases with $p_{T,h}$ and hence and cannot be captured by a global NLO K-factor.

Higher order and BSM effects



- We also see the enhancement arising from $\mathcal{O}_{tG}$ operator is scale ($p_{T,h}$) dependent.

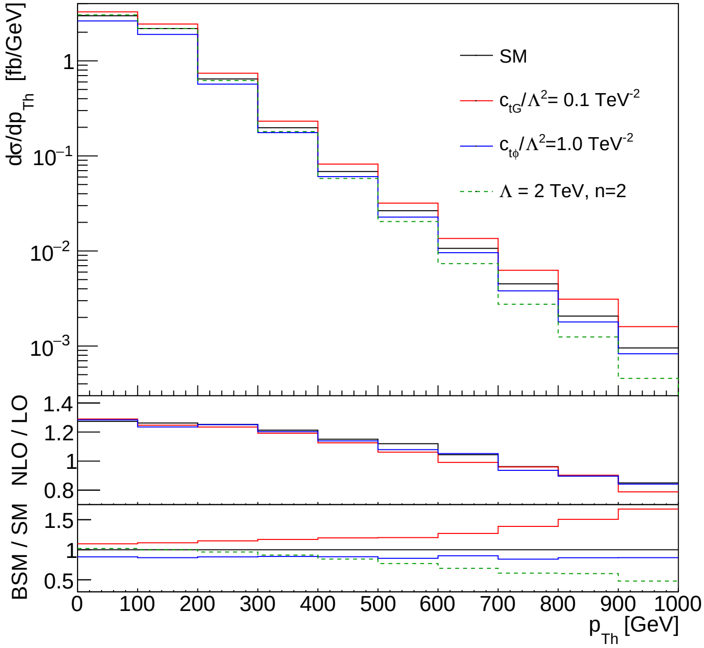
Higher order and BSM effects



- In the $t\bar{t}h$ process, $\mathcal{O}_{t\phi}$ only contributes to a shift of the top Yukawa resulting in a flat rescaling w.r.t the SM cross-section.

Higher order and BSM effects

$$\Gamma(Q^2/\Lambda^2) = \frac{1}{(1+Q^2/\Lambda^2)^n} \ , \ Q = p_{T,h}$$



- The form-factor scenario displays a depletion in cross-section at higher $p_{T,h}$, due to the dipole suppression (n=2).

Full Analysis

Full Analysis - Using jet substructure

- Our signal is $pp \to t\bar{t}h$ with the $h \to b\bar{b}$ and top-quark pair decaying leptonically. Final state is 4 b-tagged jets and 2 opp. sign leptons.
- Leading backgrounds are $t\bar{t}b\bar{b}$ and $t\bar{t}Z\,(l^+l^-)$.
- Use of jet sub-structure techniques can effectively suppress backgrounds[4].
  - We require at least 1 boosted fat jet (R=1.2) with $p_{TJ} > 200$ GeV, Higgs tagged with the BDRS algorithm.
  - Outside the fat jet we require 2 b-tagged jets (R=0.4) with $p_{Tj} > 30$ GeV; and Higgs candidate has a mass close to 125 GeV.

cuts	$t\bar{t}h$	$t\bar{t}b\bar{b}$	$t\bar{t}Z$
BDRS h-tag, $p_{T\ell} > 10$ GeV, $\lvert\eta_\ell\rvert < 3$, $n_\ell = 2$	3.32	6.35	1.02
$p_{Tj} > 30$ GeV, $\lvert\eta_j\rvert < 3$, $n_j \geq 2$, n_b=2	0.72	1.97	0.22
$\lvert m_h^{\text{BDRS}} - 125\rvert < 10$ GeV	0.15	0.14	0.009

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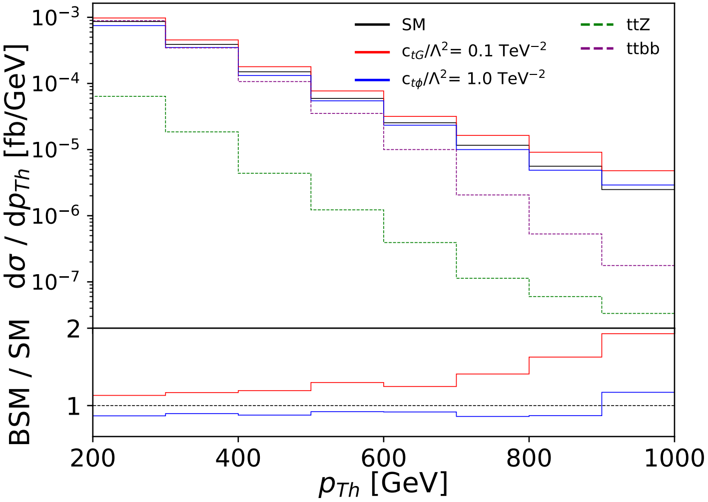
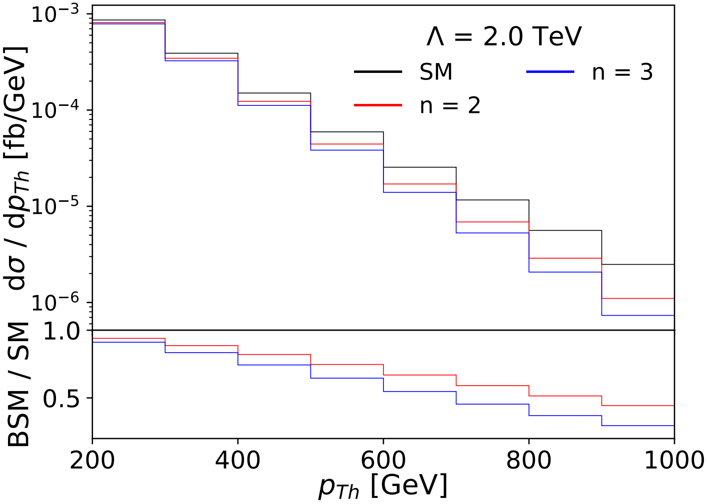
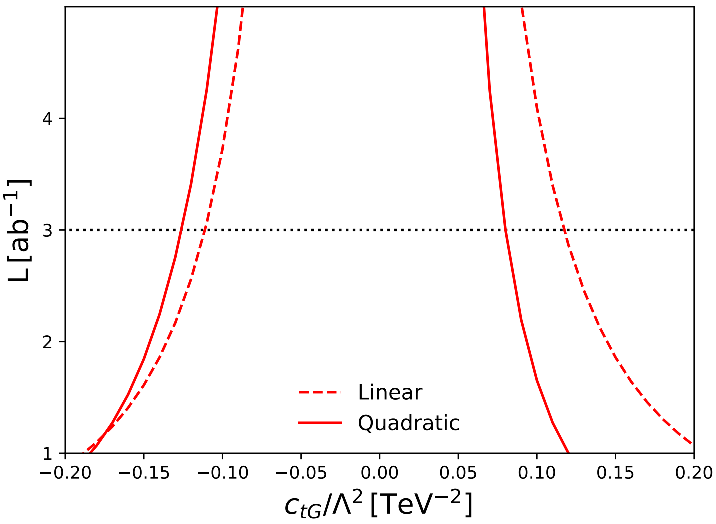
[4] Buckley, Gonçalves (2015)

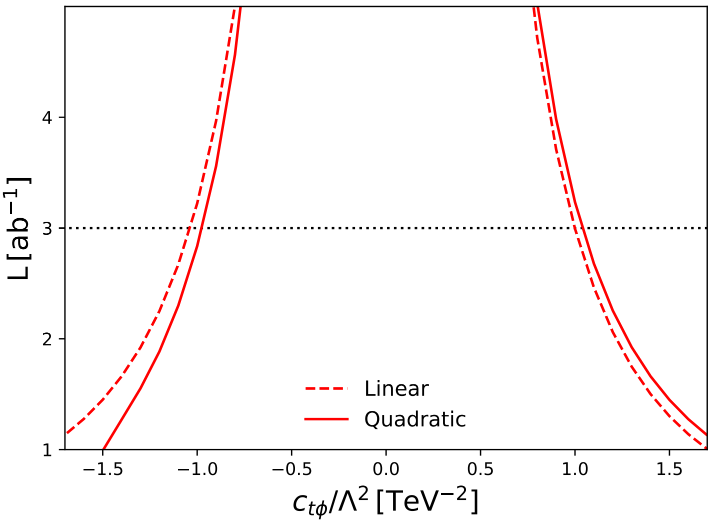
Full Analysis - EFT and form-factor



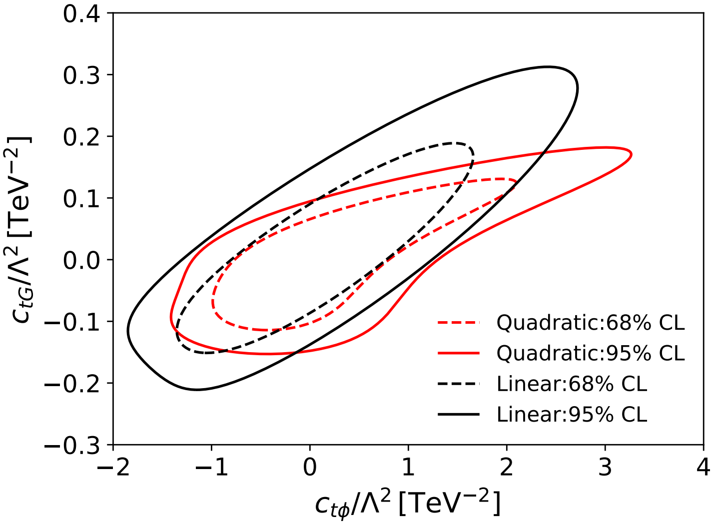


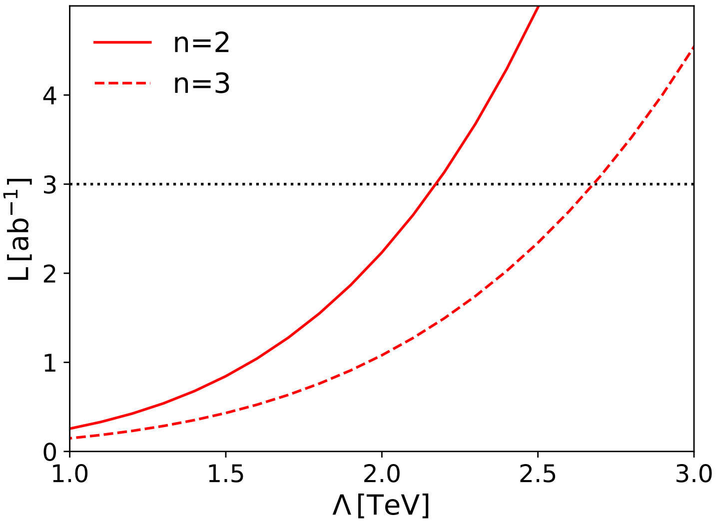
Results - Individual





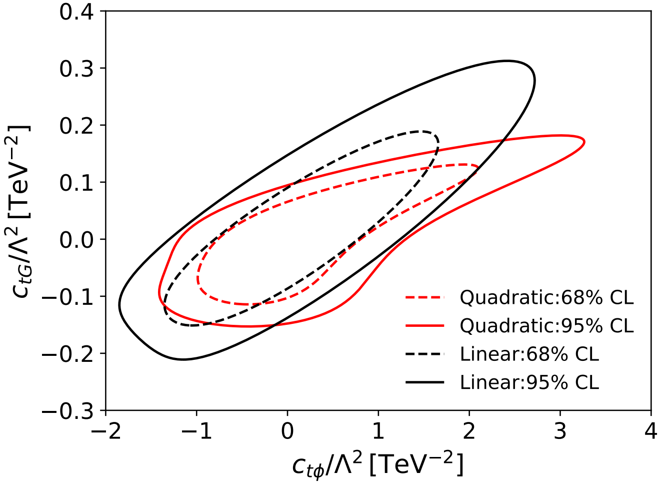
Results - Combined and form-factor

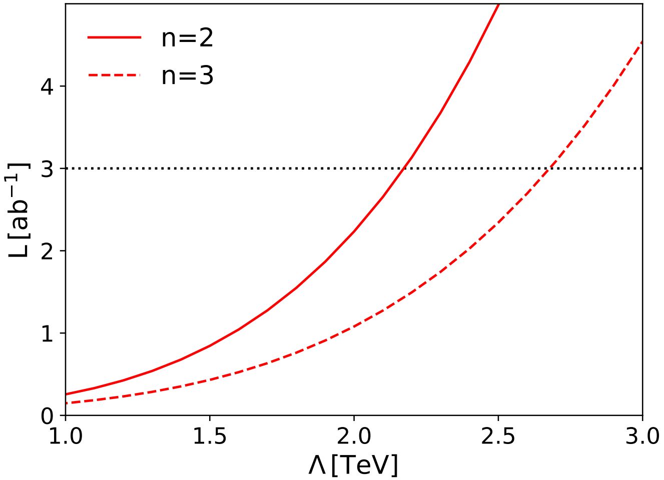




Linear order calculation is robust to quadratic effects.

Results - Combined and form-factor



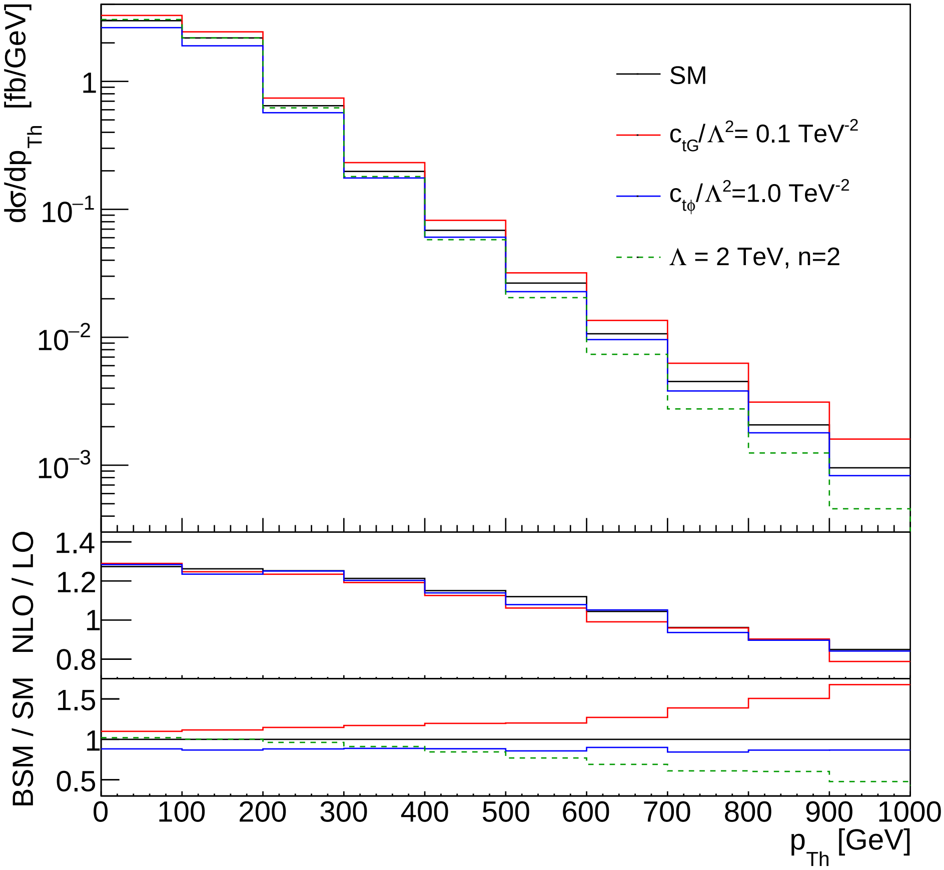


	c_i/Λ^2 [TeV^{-2}] 95% CL range	$\Lambda/\sqrt{c_i}$ [TeV] BSM scale
c_{tG} (linear)	[-0.11 , 0.12]	2.9
c_{tG} (quadratic)	[-0.13 , 0.08]	2.8
$c_{t\phi}$ (linear)	[-1.04, 1.00]	1.0
$c_{t\phi}$ (quadratic)	[-0.97 , 1.04]	1.0
n=2	*	2.1
n=3	*	2.7

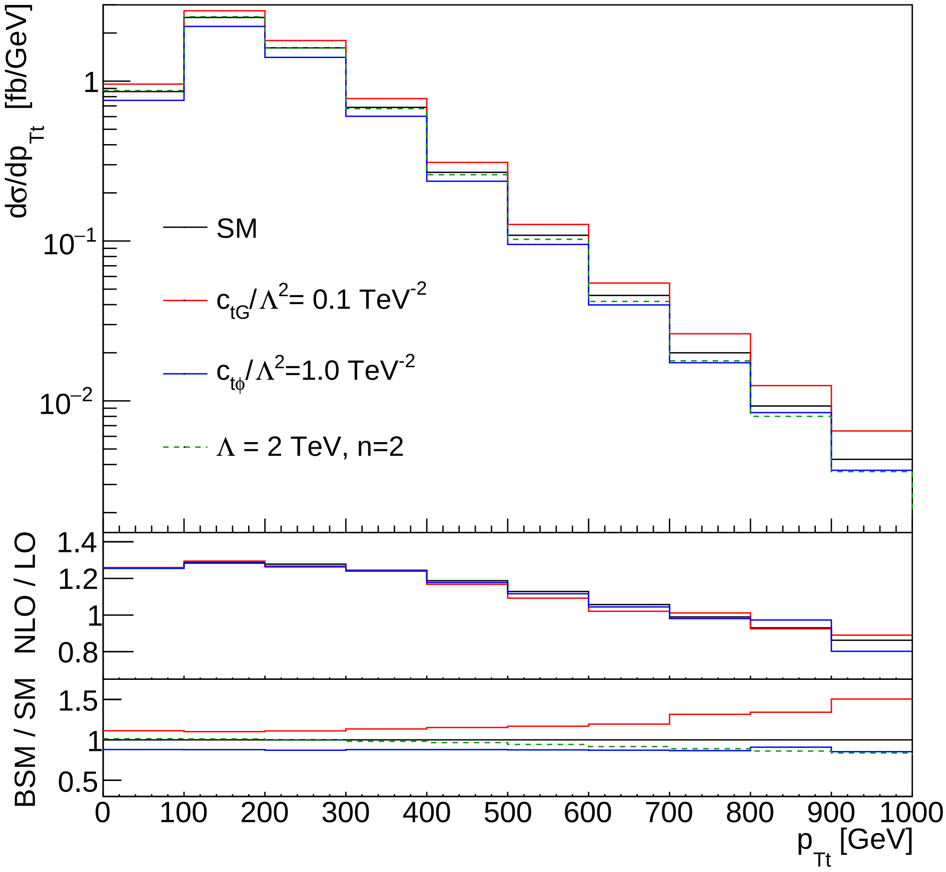
Summary

- The HL-LHC promises unprecedented precision in the top Yukawa measurement allowing one to constrain NP.
- Using the boosted Higgs regime (in the $t\bar{t}h$ channel) and jet sub structure techniques, we show how Higgs-top coupling can be *directly* probed at high scales.
- Sensitivity to new physics is presented within the EFT framework and also the Higgs-top form-factor.

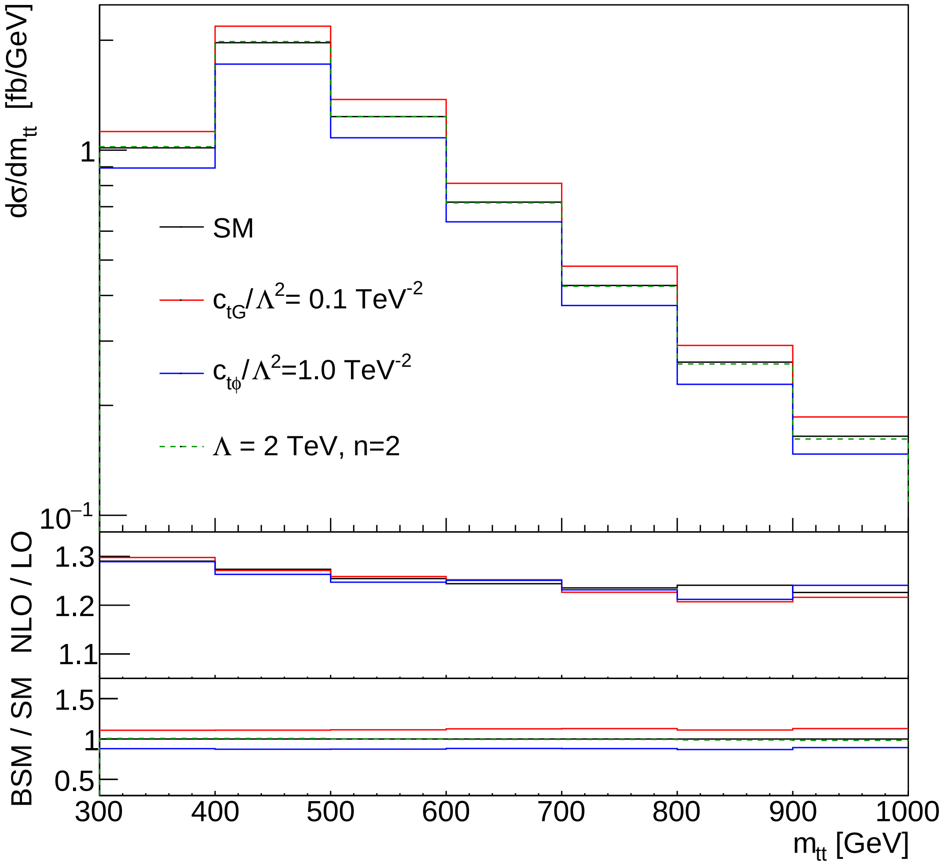
Backup Slides - More kinematic distributions, $p_{T,h}$



Backup Slides - More kinematic distributions, $p_{T,t}$



Backup Slides - More kinematic distributions, m_{tt}



Backup Slides - More kinematic distributions, m_{th}