Impact of SMEFT renormalisation group running on Higgs production at the LHC

Giuseppe Ventura

with F. Maltoni and E. Vryonidou [arXiv:*2406.06670*]

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Running and Mixing in the SMEFT

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i$$

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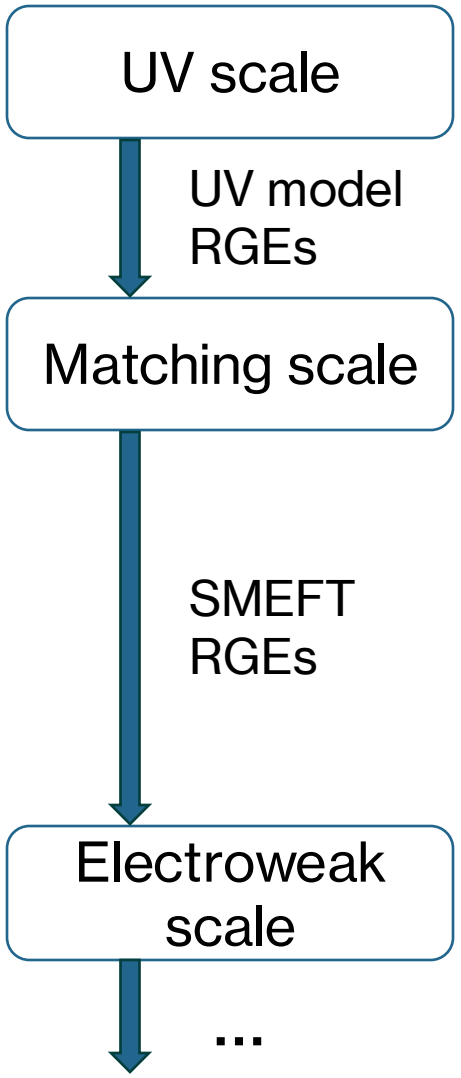
Upon renormalisation, operators run and mix with the scale as dictated by the renormalisation group equations (RGEs)



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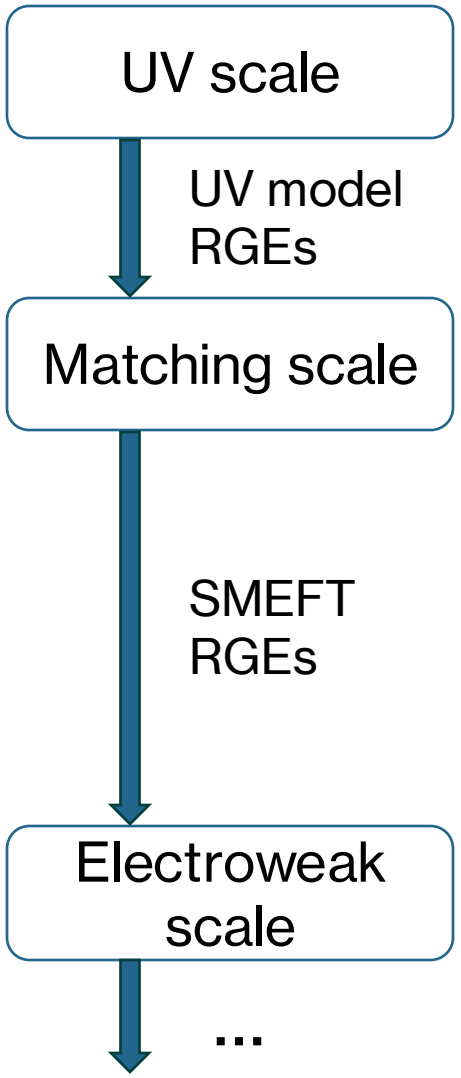
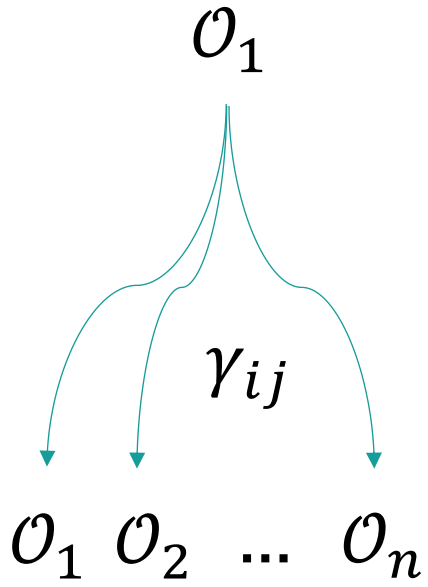
$$\frac{\mathrm{d}c_i(\mu)}{\mathrm{d}\log\mu^2} = \gamma_{ij}c_j(\mu)$$

Jenkins, Manohar and Trott
[1308.2627, 1310.4838, 1312.2014]





Effects of RGEs in the SMEFT

$$\sigma_{\text{SMEFT}} = \sigma_{\text{SM}} + \sum_i \frac{c_i(\mu)}{(\Lambda/1\ \text{TeV})^2}\sigma_i(\mu) + \sum_{i\leq j} \frac{c_i(\mu)c_j(\mu)}{(\Lambda/1\ \text{TeV})^4}\sigma_{ij}(\mu)$$

$$c_i(\mu) = \Gamma_{ij}(\mu, \mu_0)c_j(\mu_0)$$

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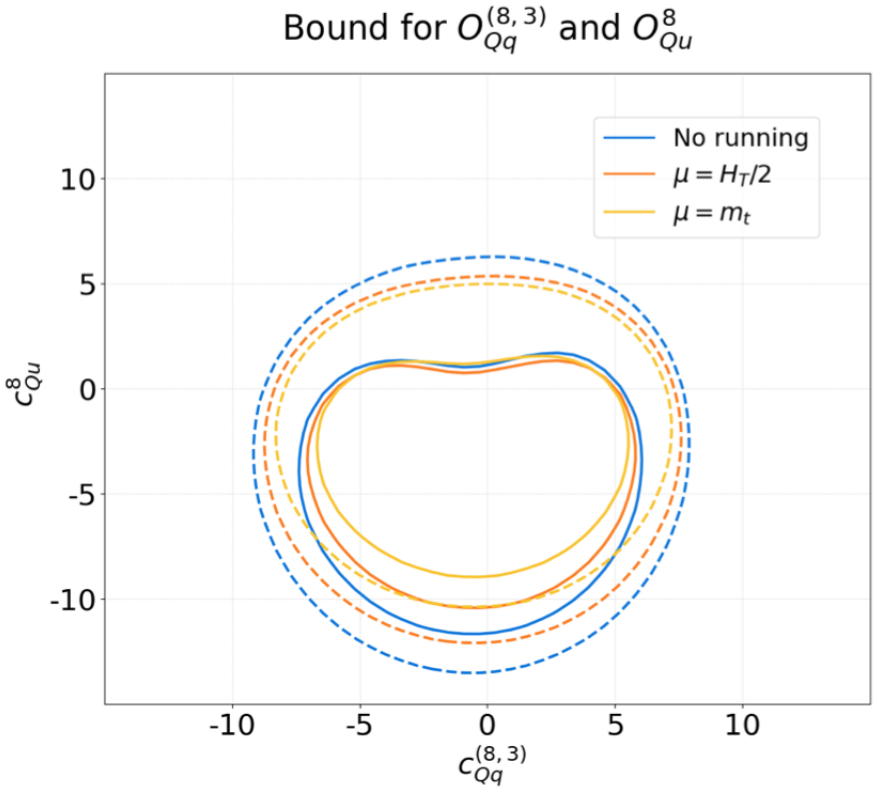

Different choices of the renormalisation scale μ can impact observables and bounds on Wilson coefficients

Plot from Aoude, Maltoni, Mattelaer, Severi and Vryonidou [arXiv:2212.05067]

See also:
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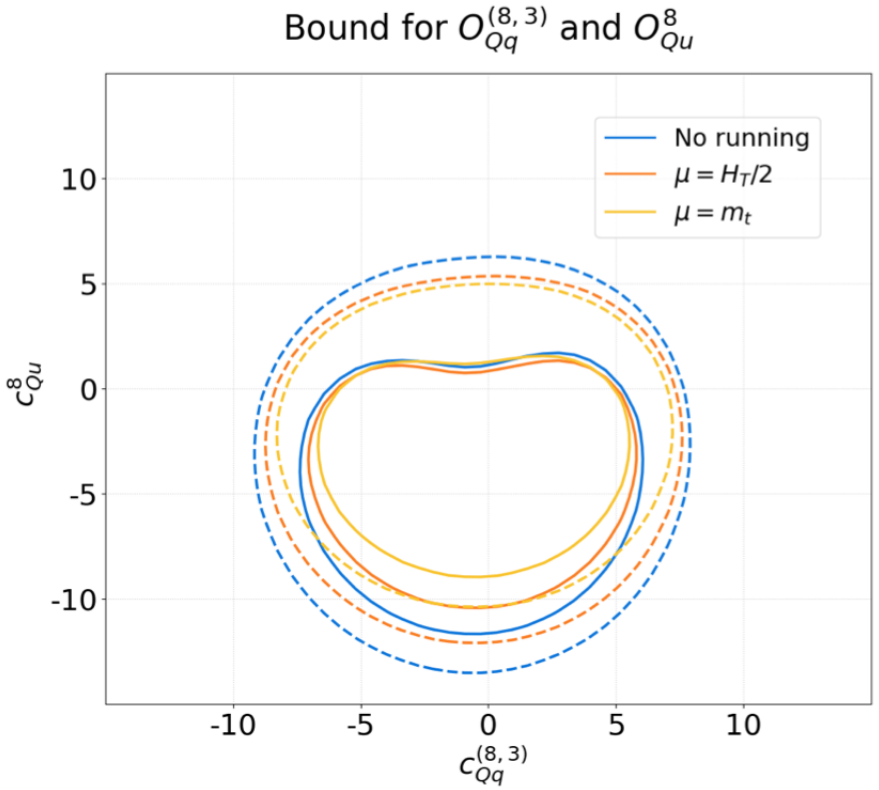

Different choices of the renormalisation scale μ can impact observables and bounds on Wilson coefficients

- We extend the study of (QCD-induced) RG effects by considering the impact on Higgs observables at the LHC, and on constraints of relevant Wilson coefficients

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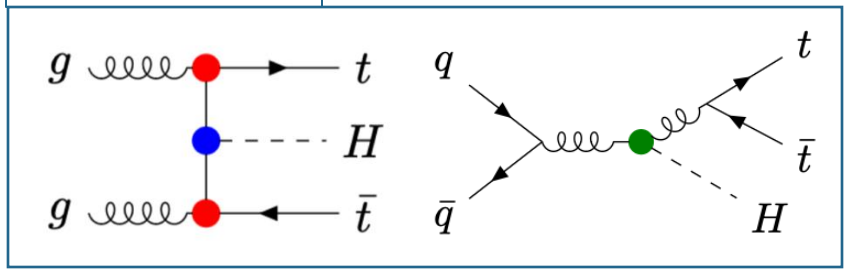
SMEFT contribution to Higgs observables

$pp \to t\,\bar{t}\,h$



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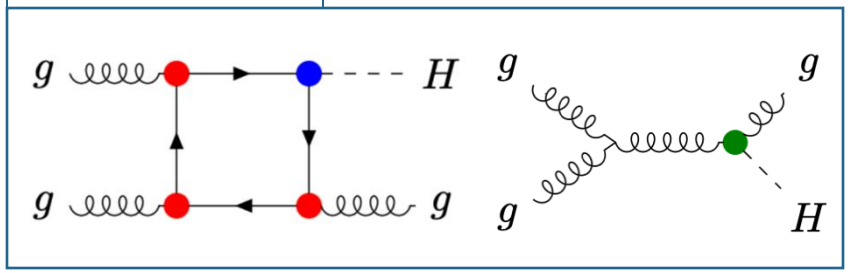

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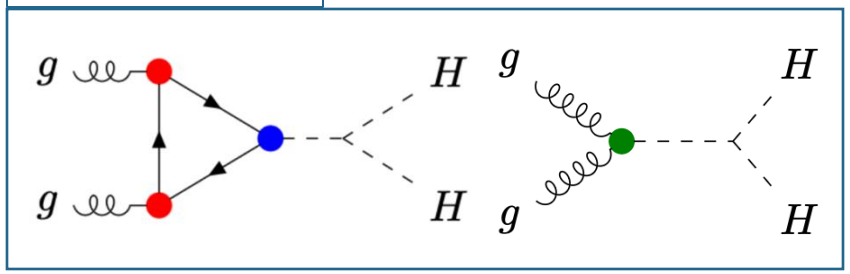

Leading contribution from:

$$\mathcal{O}_{\varphi G} = \left(\varphi^\dagger\varphi - \frac{v^2}{2}\right) G^a_{\mu\nu} G_a^{\mu\nu}$$

→ Induces tree-level diagrams for hh and hj

$$\mathcal{O}_{t\varphi} = \left(\varphi^\dagger\varphi - \frac{v^2}{2}\right) \bar{Q}\tilde{\varphi}t + \text{h.c.}$$

$$\mathcal{O}_{tG} = ig_s(\bar{Q}\tau^{\mu\nu}T^a\tilde{\varphi}t)G^a_{\mu\nu} + \text{h.c.}$$

→ Divergences in hh and hj reabsorbed by $\mathcal{O}_{\varphi G}$

↓

$\mathcal{O}_{tG}$-inserted cross-section terms will depend on the renormalisation scale μ

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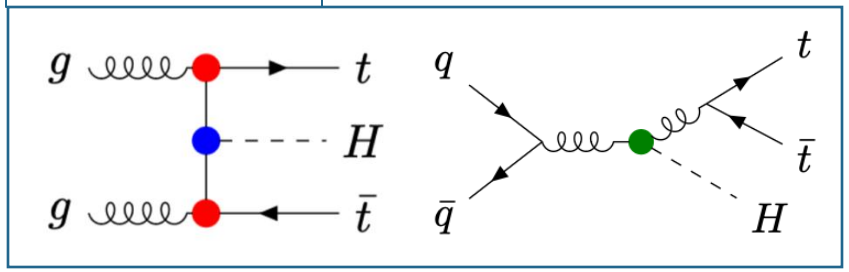

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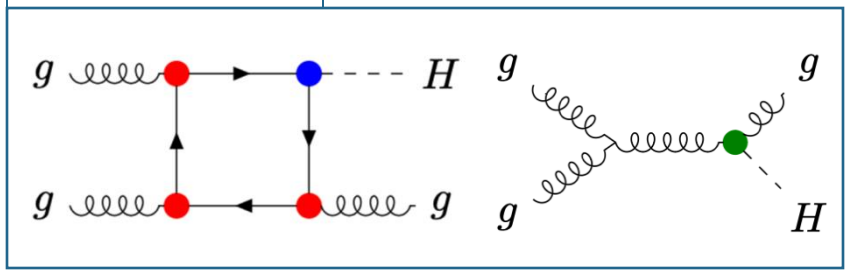

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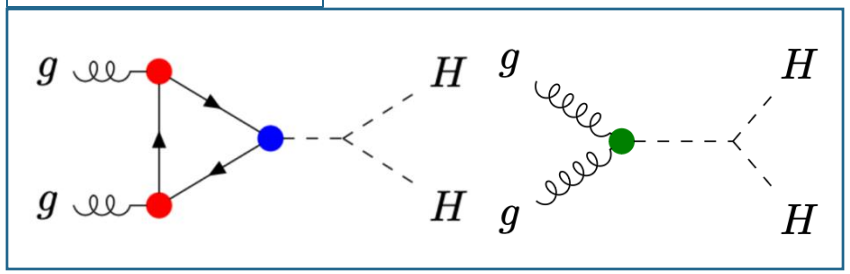

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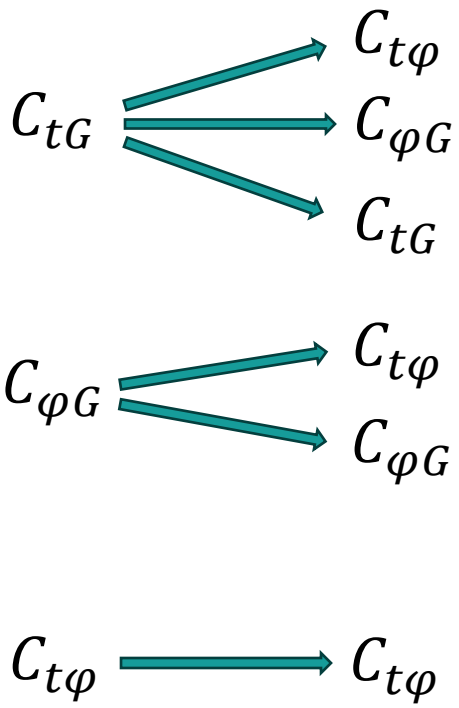
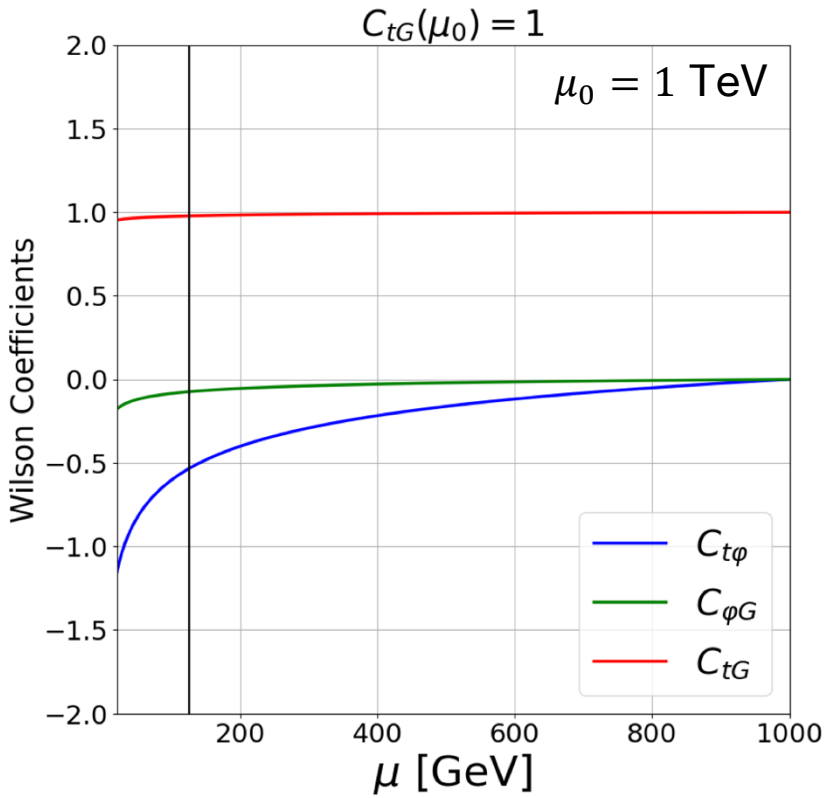
↓ Closed under QCD-induced anomalous dimension matrix

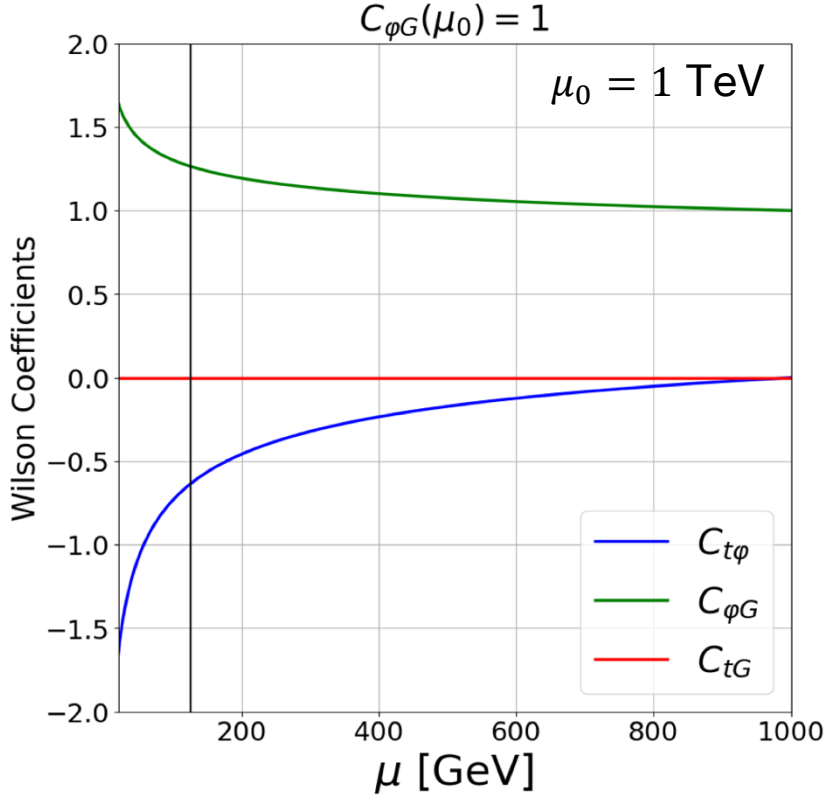
Maltoni, Vryonidou and Zhang [arXiv: 1607.05330]

↓ $\mathcal{O}_{tG}$-inserted cross-section terms will depend on the renormalisation scale μ

Mixing structure







Impact of scale choice on distributions

SM and EFT cross-sections computed with MadGraph and SMEFT@NLO ($\mu_0 = 1$ TeV)

Scale choices
- Dynamical scale (event-by-event variation)
- Fixed scale ($\mu_0 \to \mu$)
- No running ($\mu_0 = \mu = 1$ TeV)

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		Variation (up to)	
	$pp \to h\,j\,(h\,h)$	**Linear**	**Quadratic**
Benchmarks	$c_{t\varphi}(\mu_0) = 1$	10%	20%
	$c_{\varphi G}(\mu_0) = 1$	20%	35%
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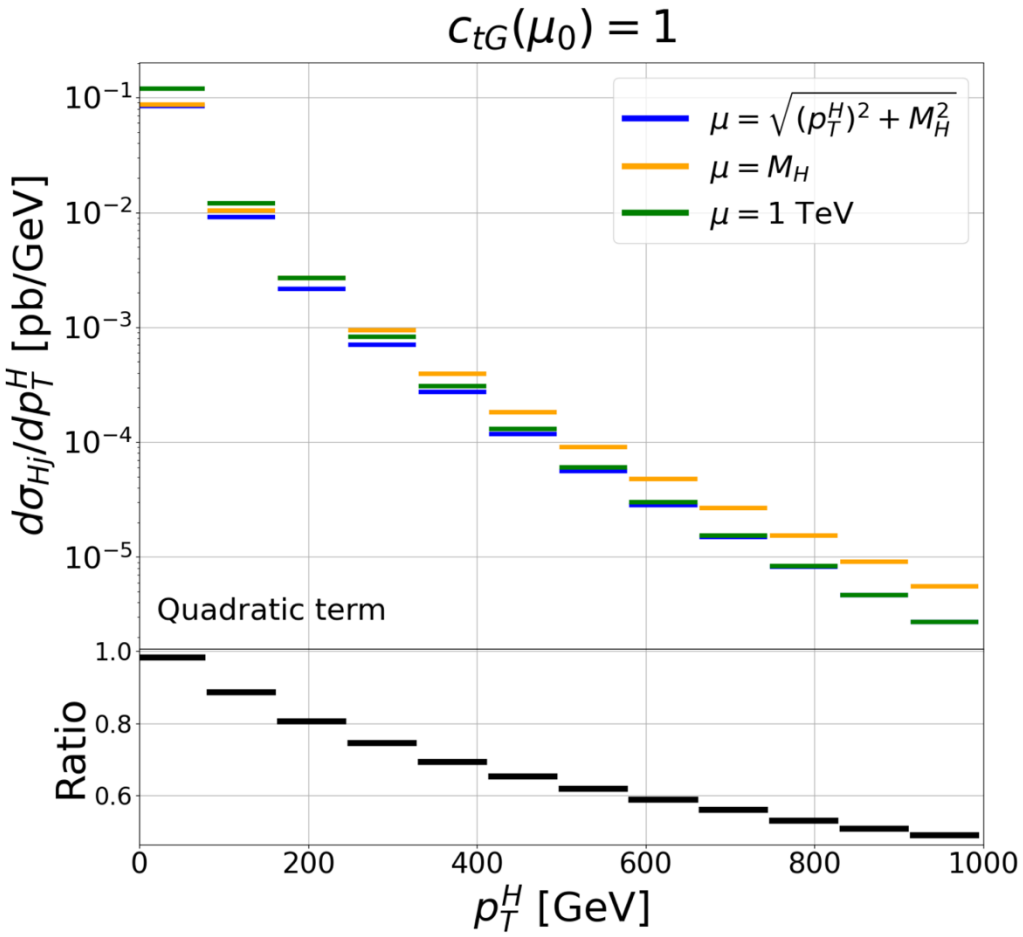
Variation consistent with the self-running of the coefficients (same for $\bar{t}th$)



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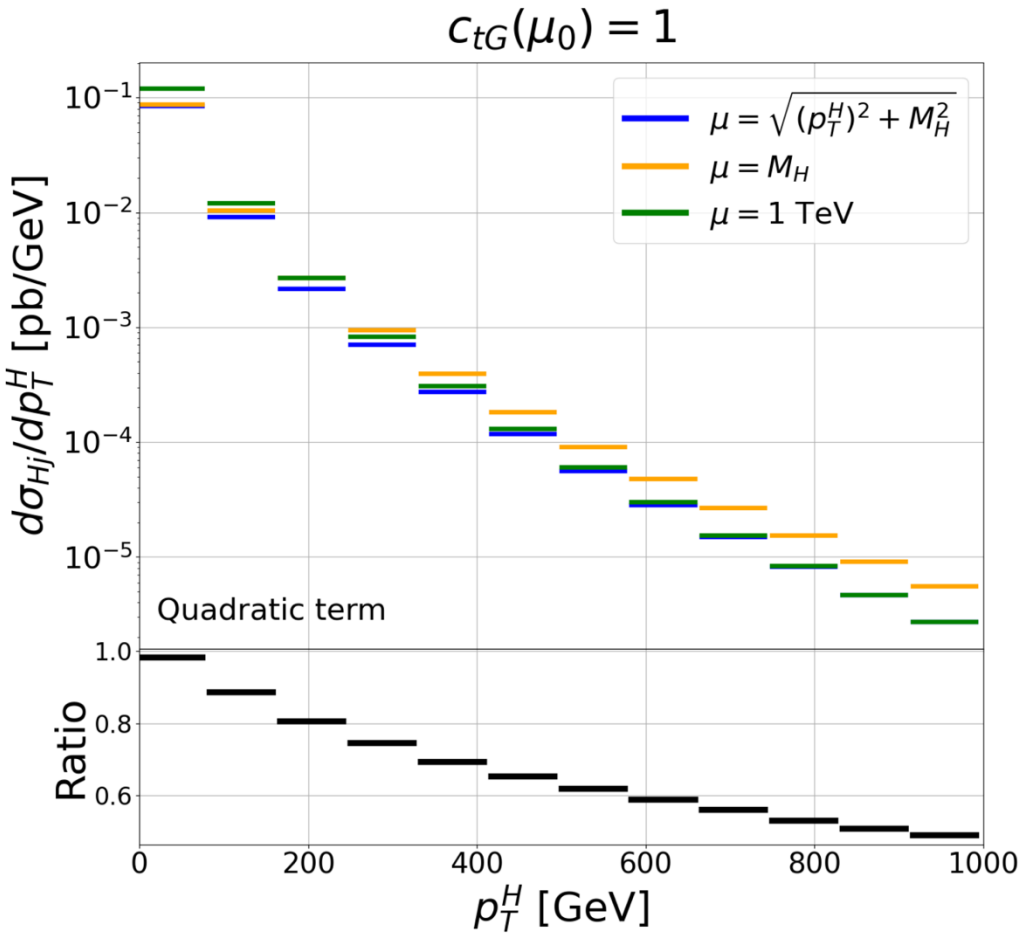
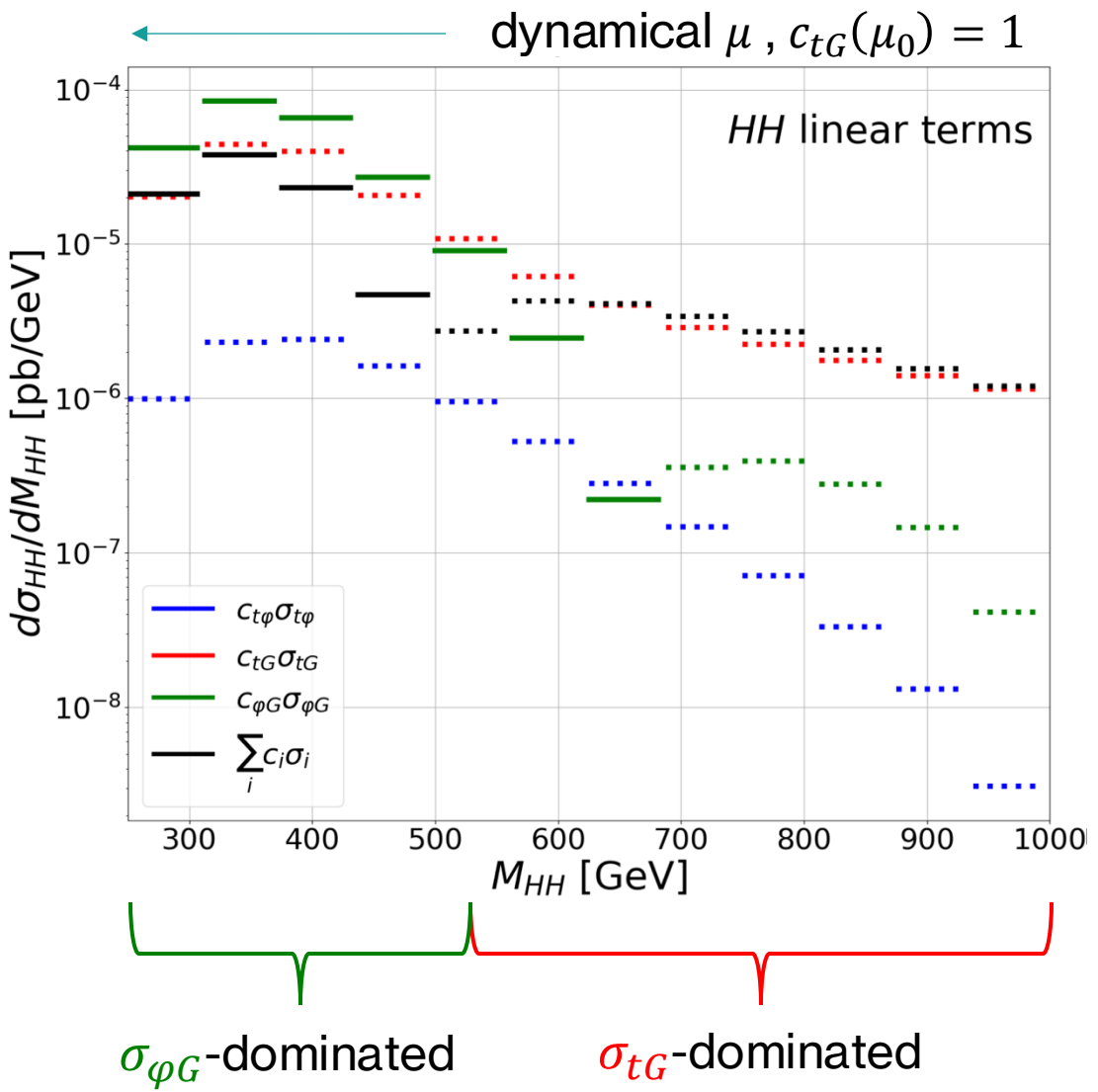
$\mathcal{O}_{tG}$ causes the biggest impact in loop-induced processes (order 1% for $\bar{t}th$)



Mixing effects in loop-induced processes

When $c_{tG}(\mu_0) \neq 0$, the RGEs will activate $\mathcal{O}_{\varphi G}$ inducing tree-level contributions resulting in a strong mixing among different terms



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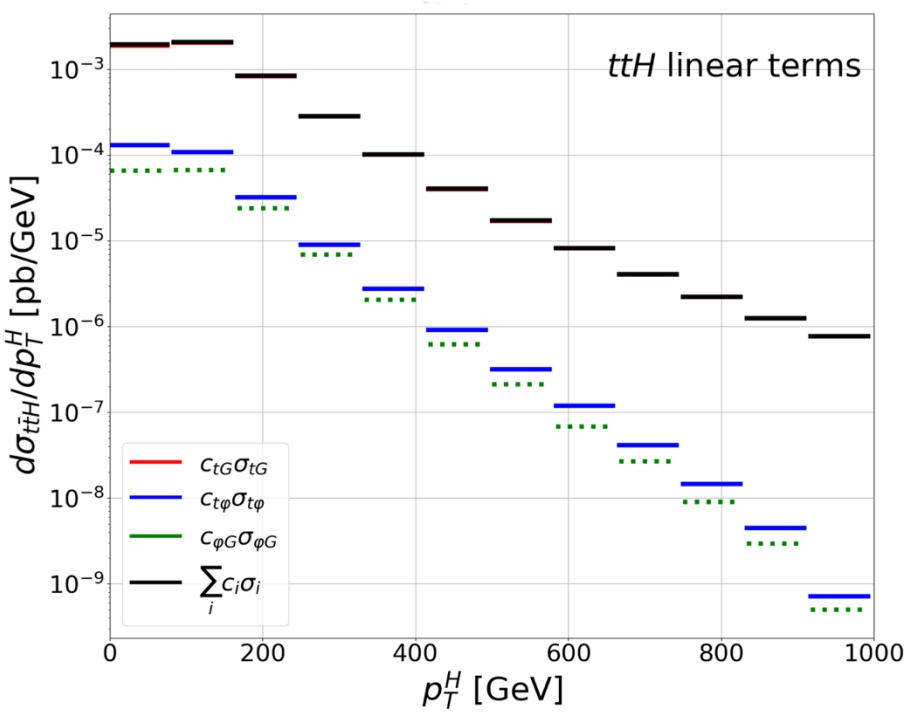
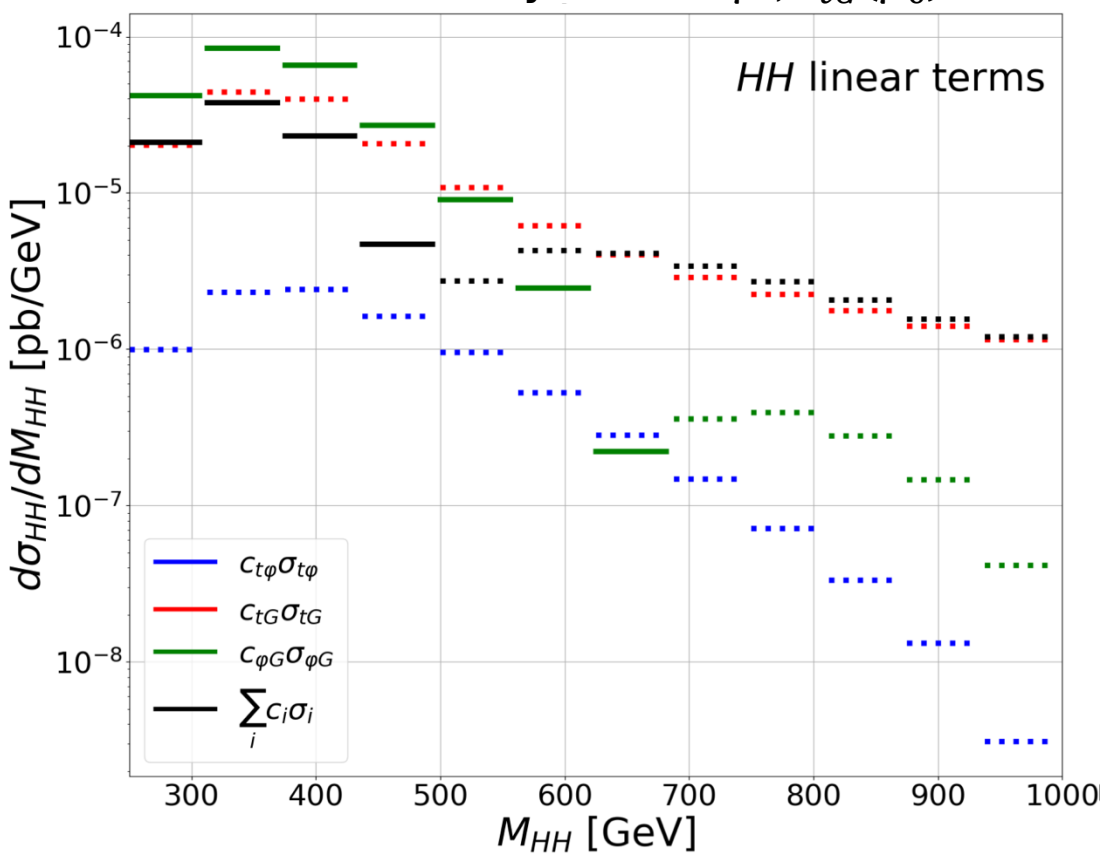


Different behaviour for $t\bar{t}h$, sub-leading mixing effects

dynamical μ , $c_{tG}(\mu_0) = 1$



$\sigma_{\varphi G}$-dominated σ_{tG}-dominated

Impact of RGEs on bounds : current data

Toy fit of differential p_T^H spectrum to inclusive data from ATLAS and CMS* ($p_T^H > 200$ GeV)

Constraints extracted at $\mu_0 = 1$ TeV

Marg.	μ dynamical	$\mu = M_H$	$\mu = 1$ TeV
$c_{t\varphi}$	[-21.00,50.15]	[-19.56,46.98]	[-21.17, 53.69]
$c_{\varphi G}$	[-0.095, 0.092]	[-0.085, 0.081]	[-0.10, 0.095]
c_{tG}	[-0.68, 0.69]	[-0.70, 0.65]	[-0.77, 0.49]

Enhanced constraints for $c_{t\varphi}$ and $c_{\varphi G}$

*[arXiv: 2006.13251, arXiv: 2111.08340]

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Different behaviour for c_{tG}, biggest variation when running is activated

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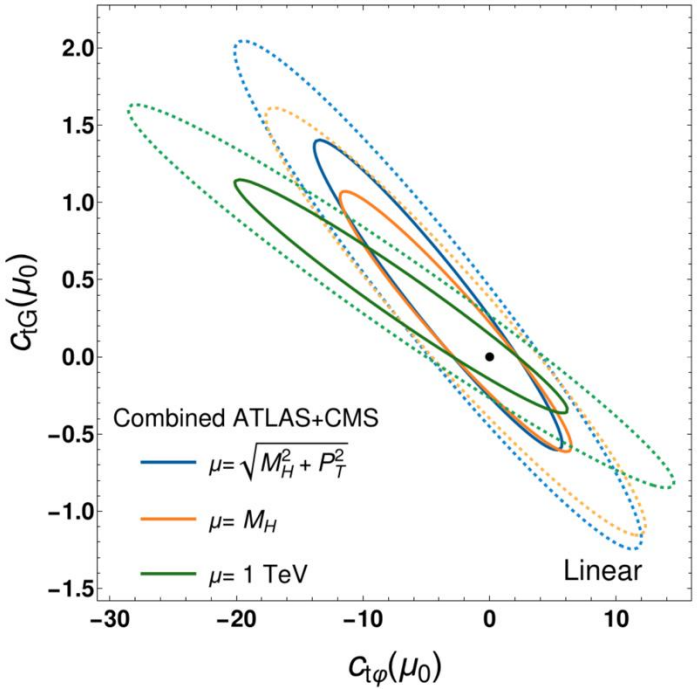
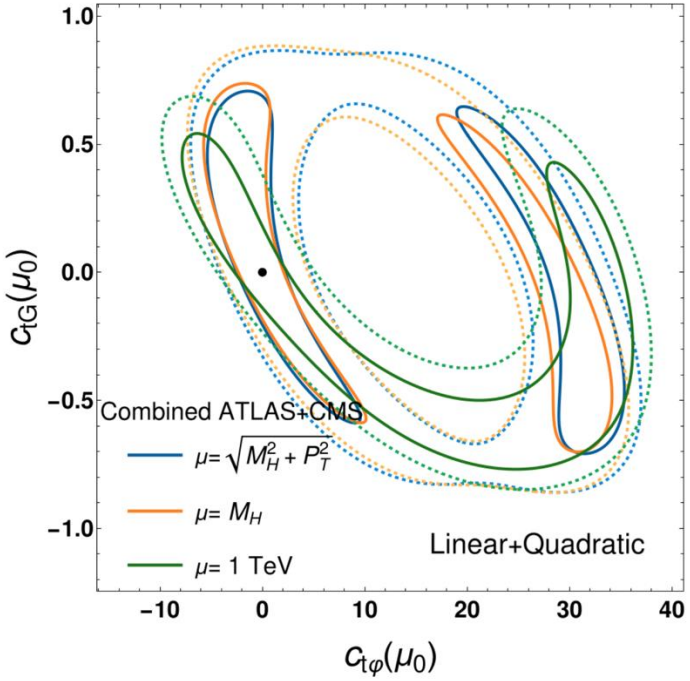
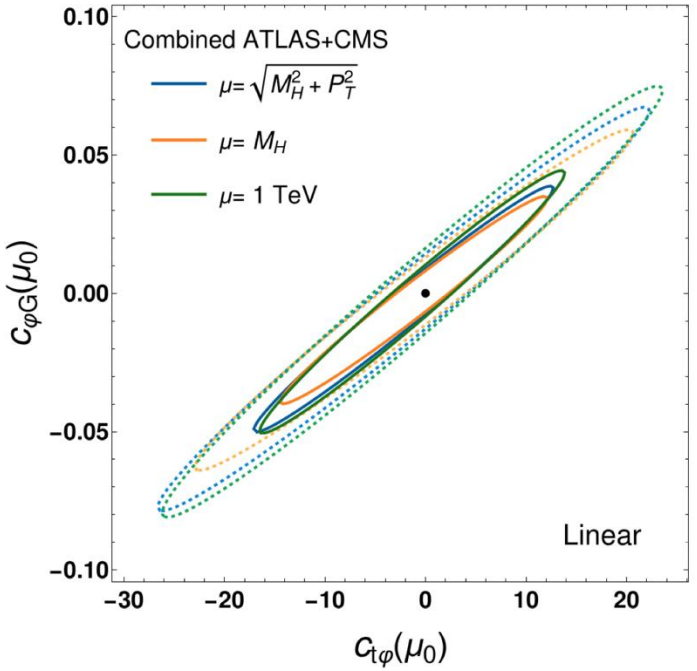
Impact of RGEs on bounds : current data

Solid 68% C.L.
Dashed 95% C.L.





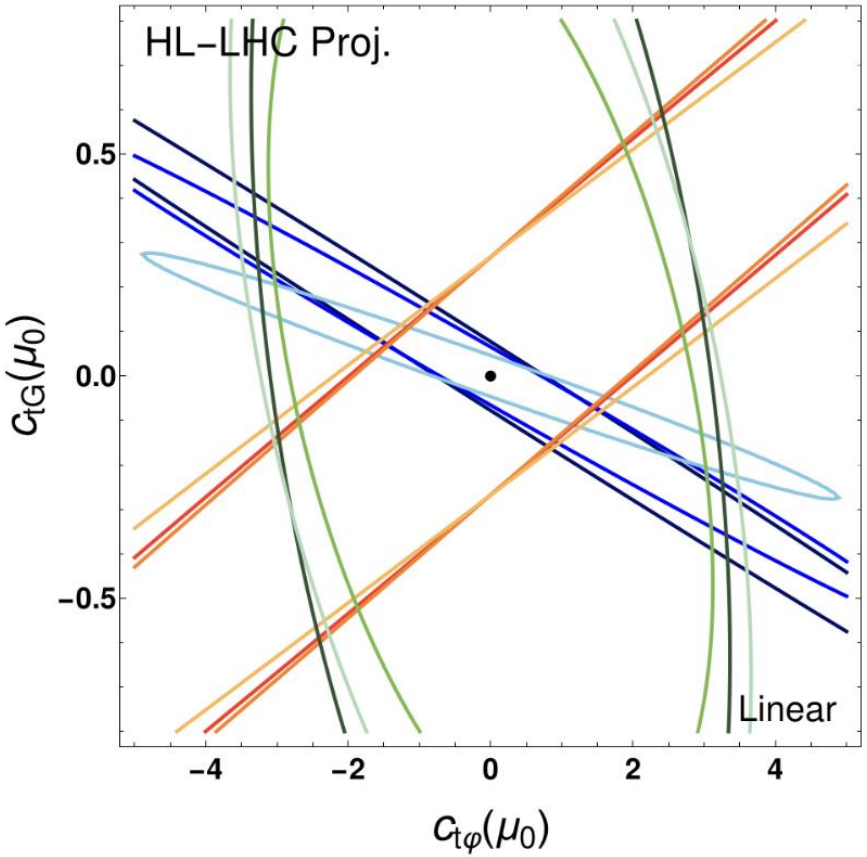


Impact on correlations between coefficients, flat directions get rotated in the EFT parameter space

Much smaller effect when the dipole operator is excluded

Impact of RGEs on bounds : HL-LHC

Toy fit with projected uncertainties for inclusive p_T^H spectrum, $t\,\bar{t}\,h$ differential cross-section and HH cross-section [arXiv: 1902.00134]



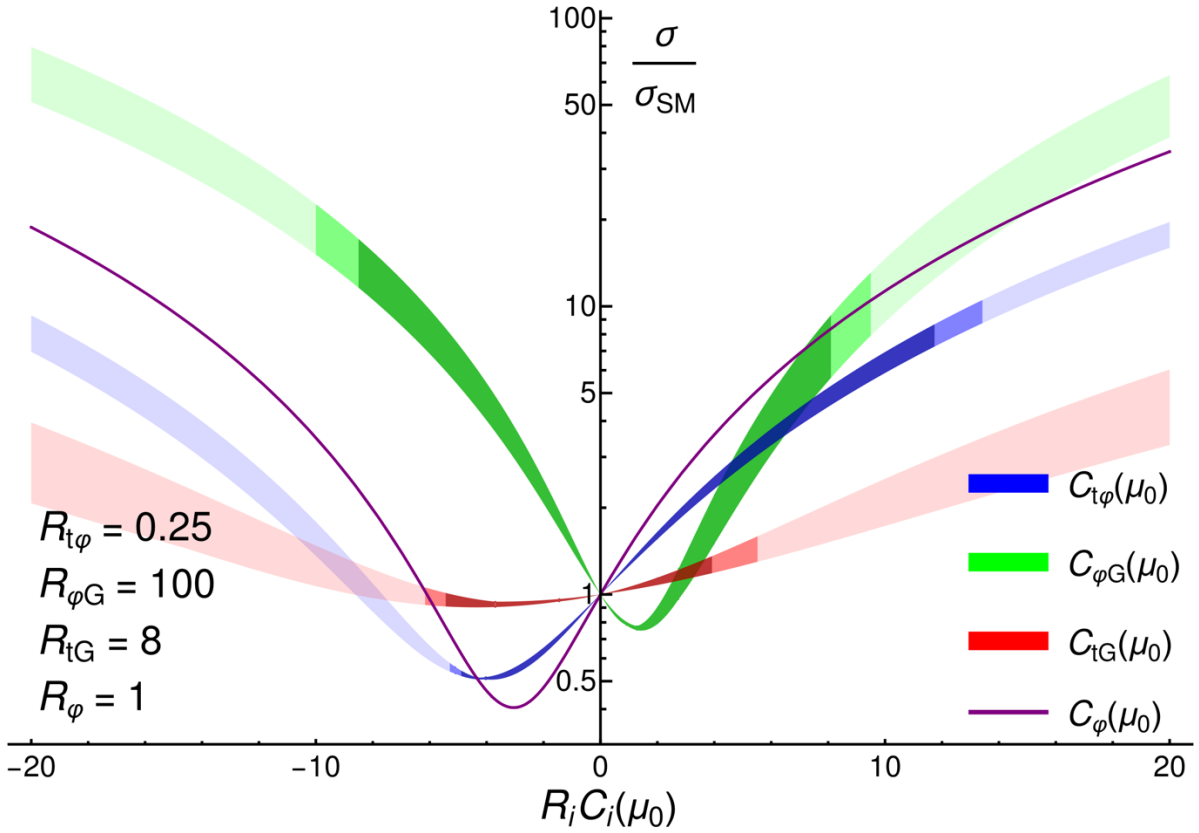
Marginalised	μ dynamical	$\mu = M_H$	$\mu = 1$ TeV (no running)
$c_{t\varphi}$	[-2.02, 2.24]	[-1.95, 2.18]	[-1.69, 1.59]
$c_{\varphi G}$	[-0.012, 0.012]	[-0.012, 0.012]	[-0.010, 0.0083]
c_{tG}	[-0.25, 0.21]	[-0.26, 0.22]	[-0.13, 0.11]

Bound for c_{tG} widened by a factor of 2 when running is activated

HH production and impact on Higgs self-interaction

Double Higgs production probes Higgs trilinear coupling at hadron colliders, which is modified by $\mathcal{O}_\varphi$

$$O_\varphi = \left(\varphi^\dagger\varphi - \frac{v^2}{2}\right)^3$$



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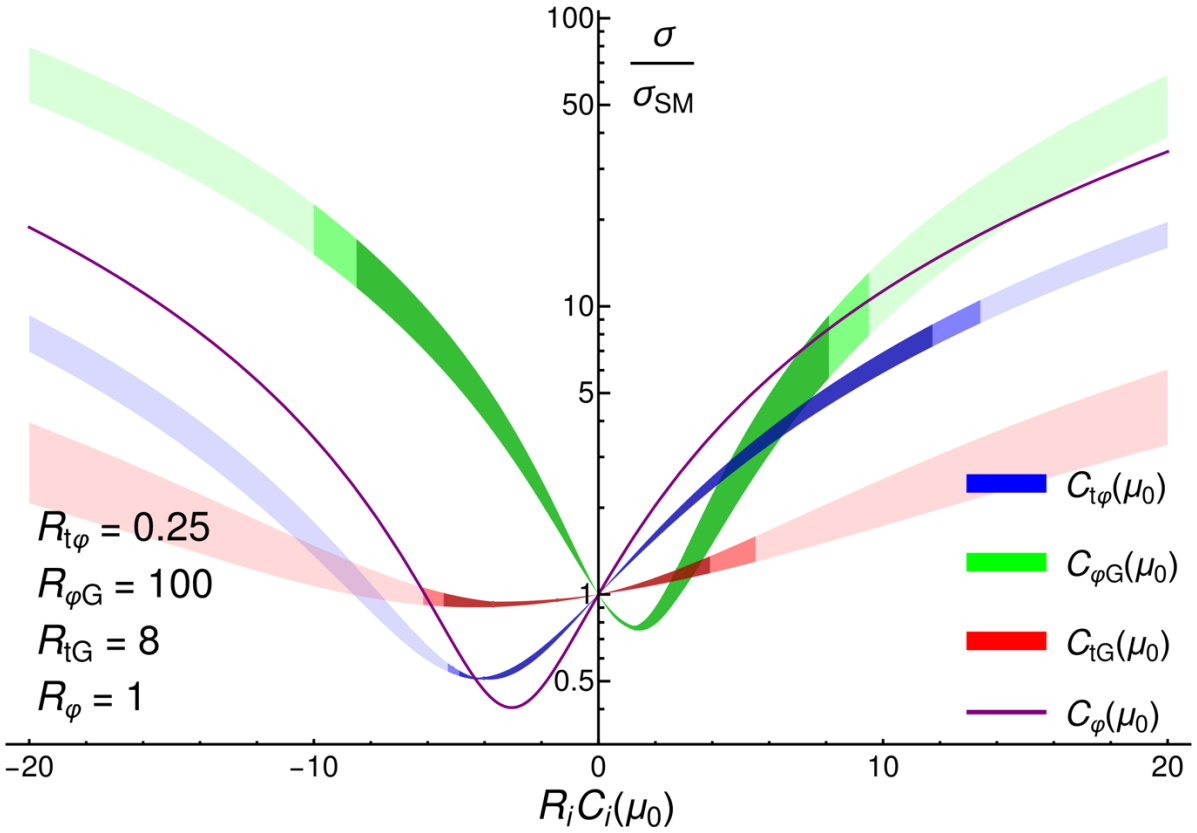
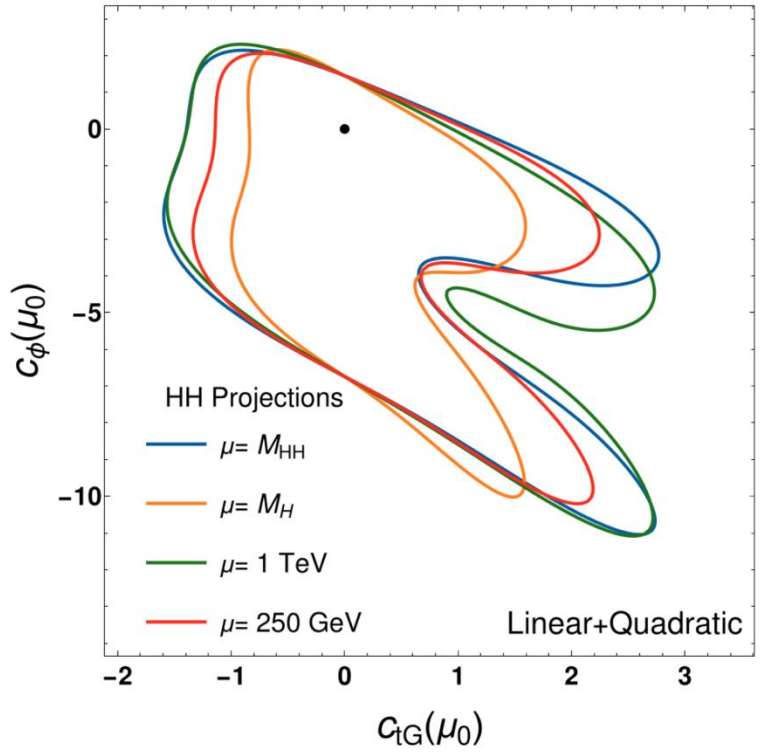
Does not run under QCD, impact of scale choice through marginalisation





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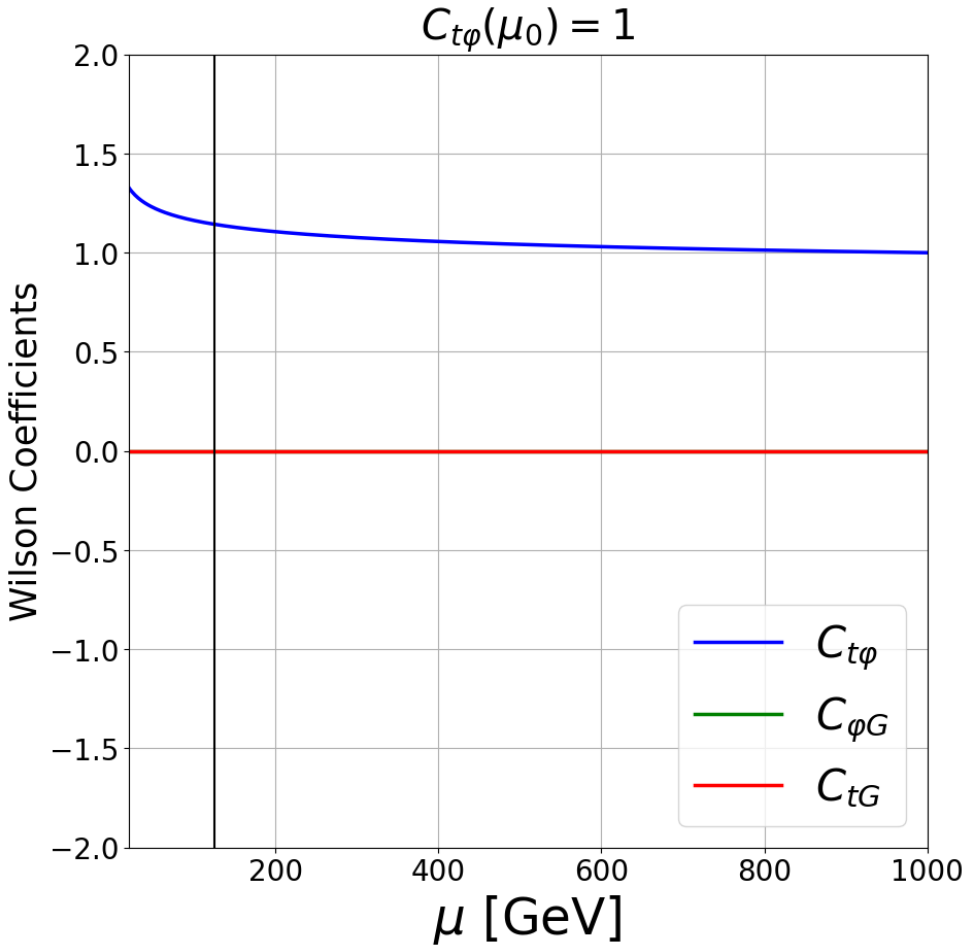
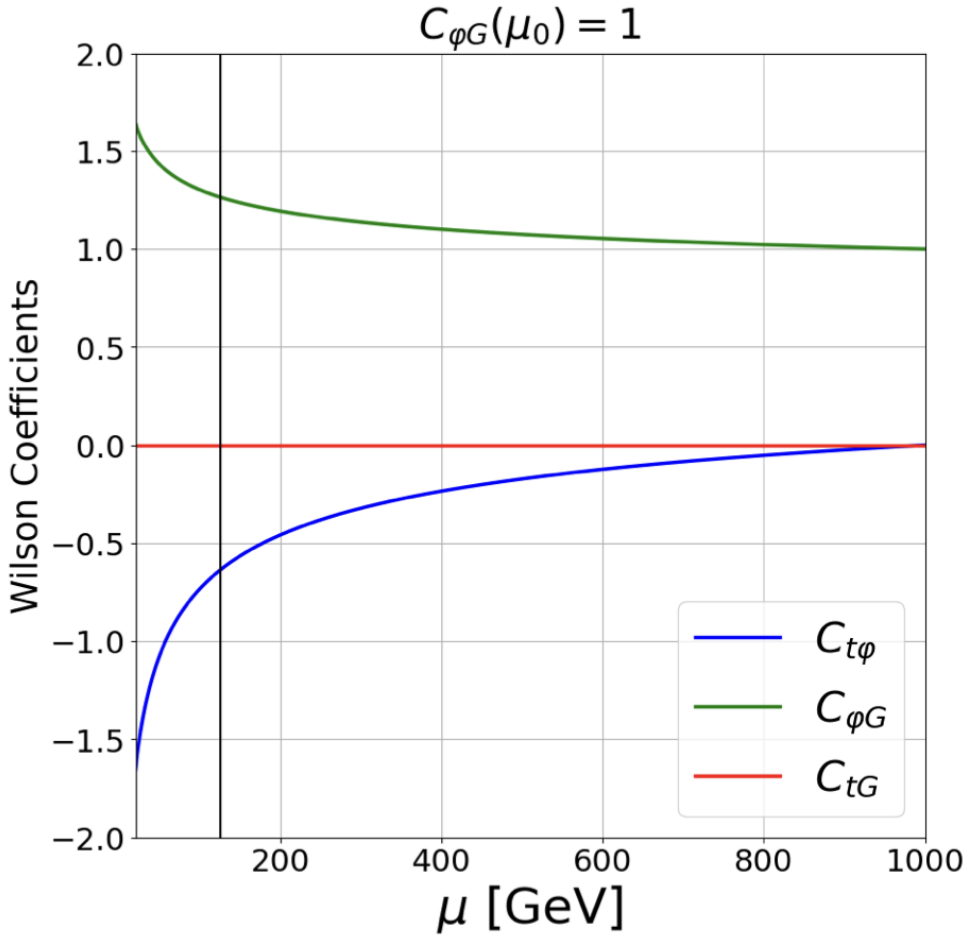
Thank you

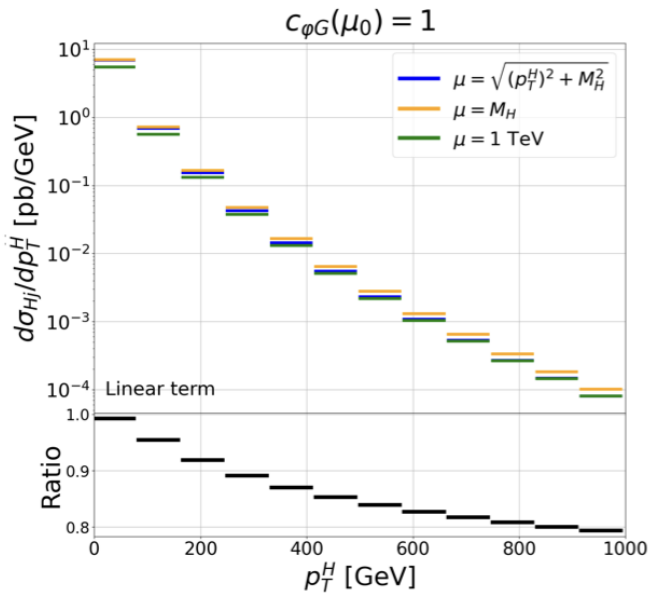
BACKUP

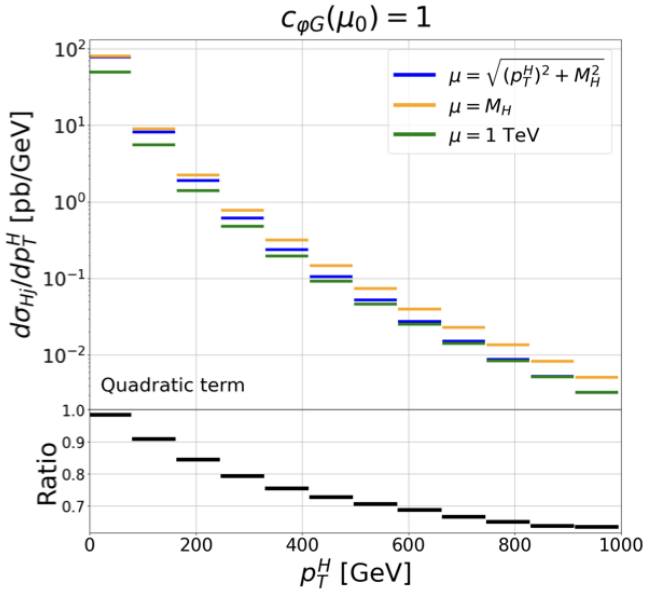
Running of the couplings

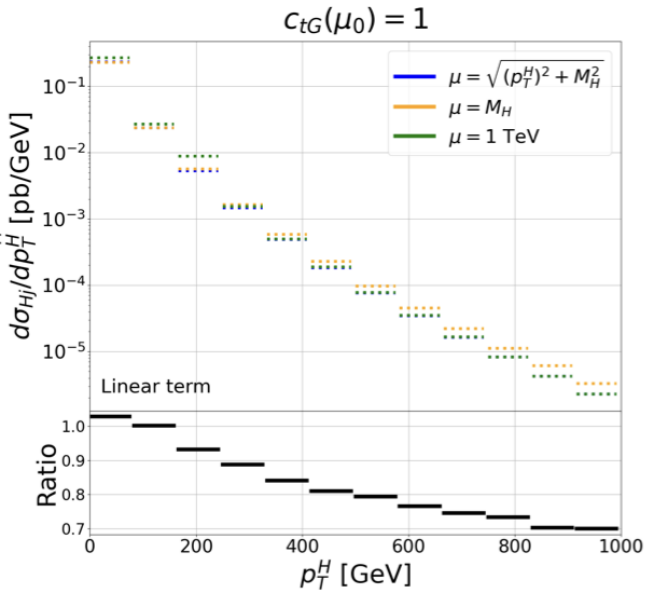


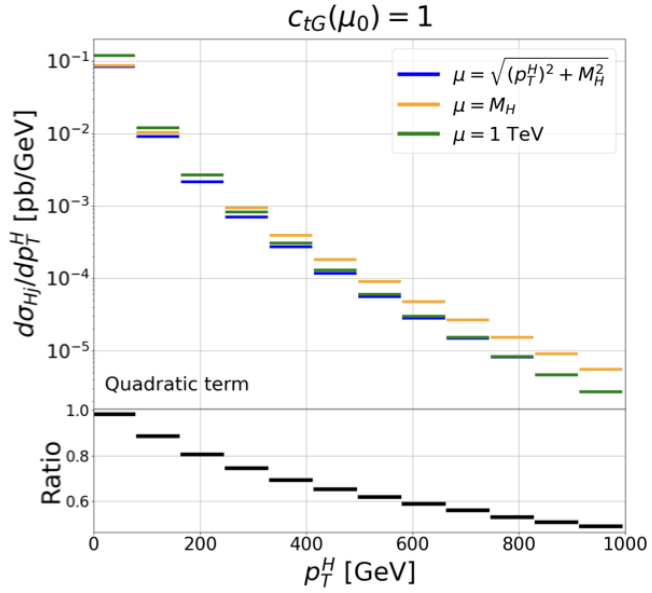


Differential distributions: Hj

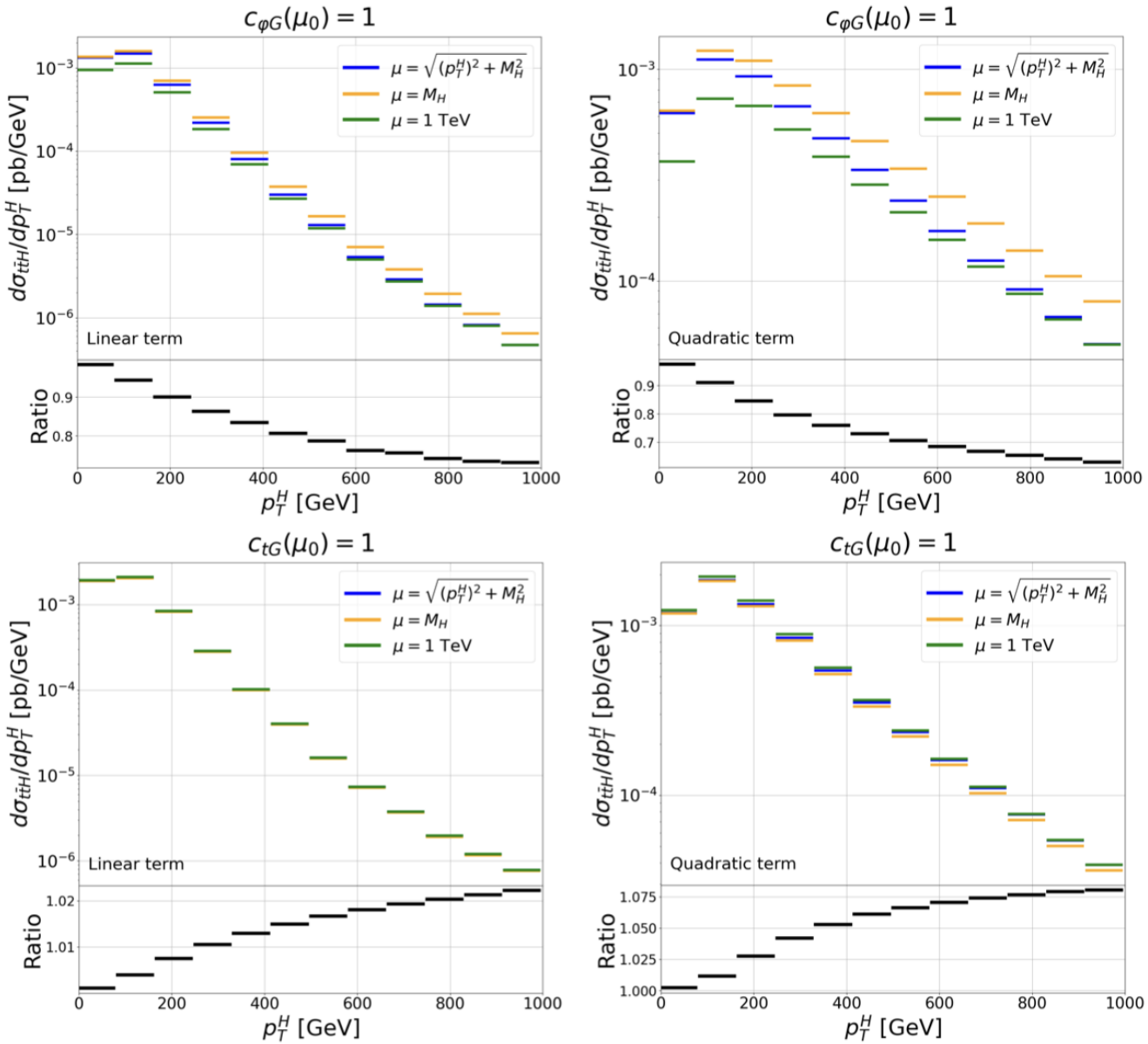




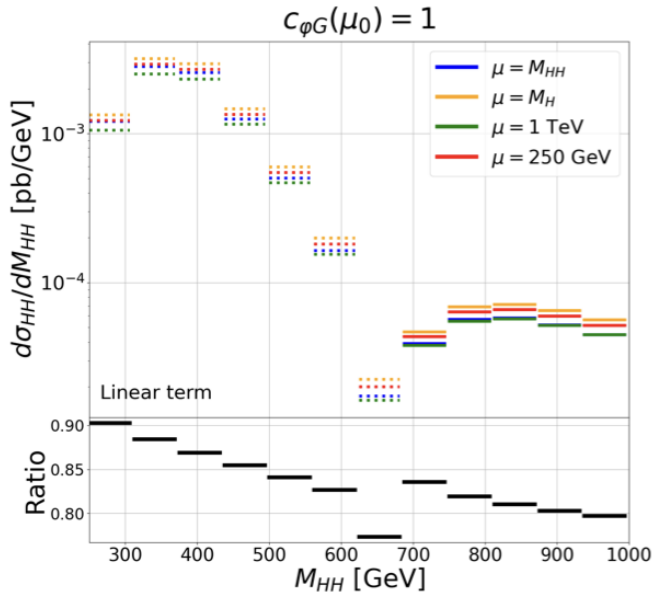


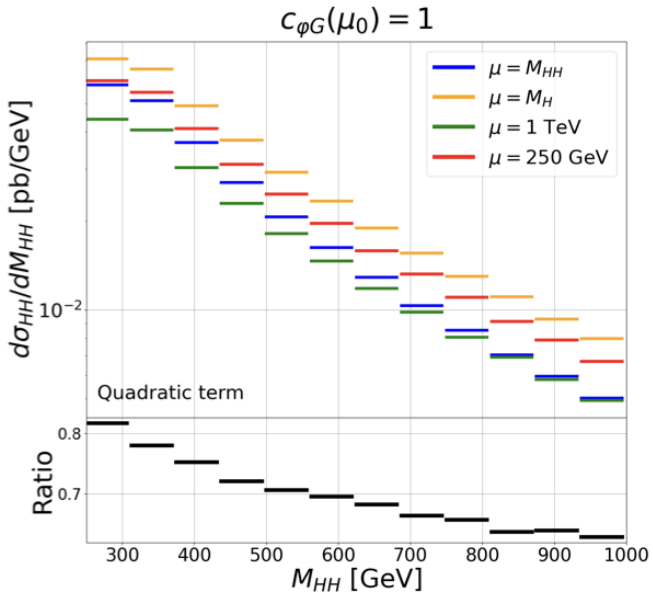


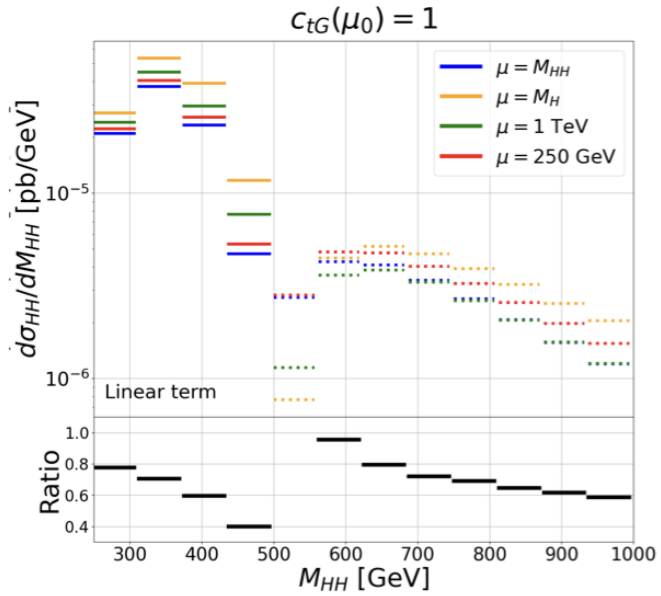
Differential distributions: $\bar{t}th$

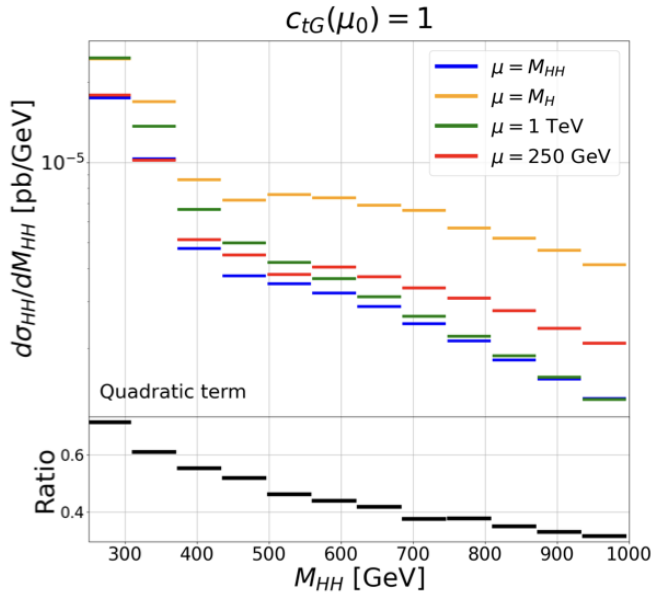


Differential distributions: hh

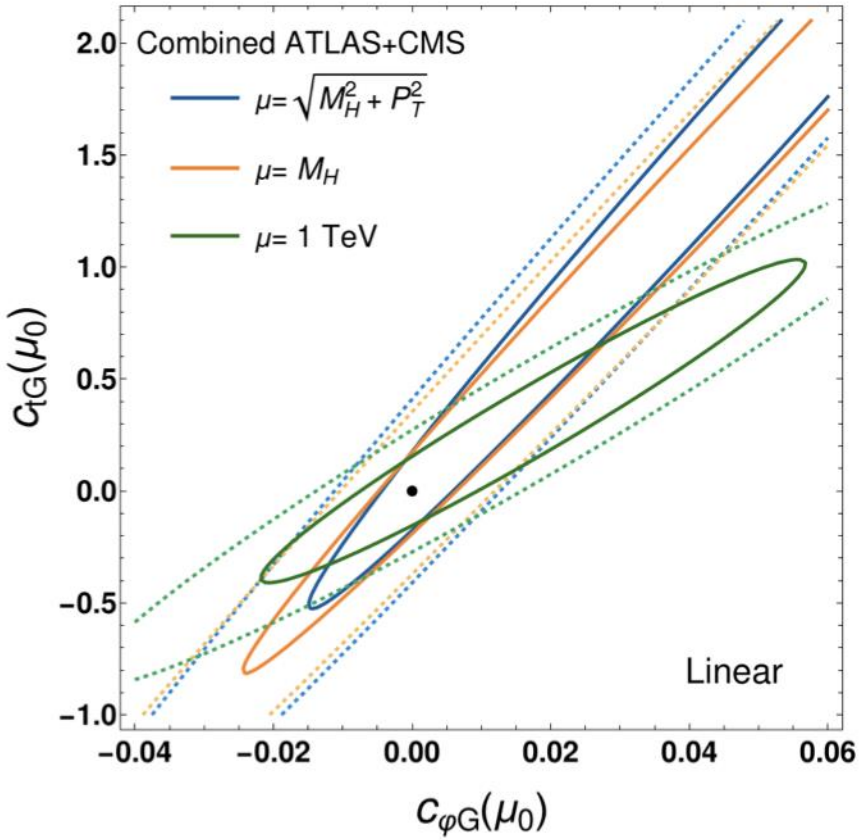


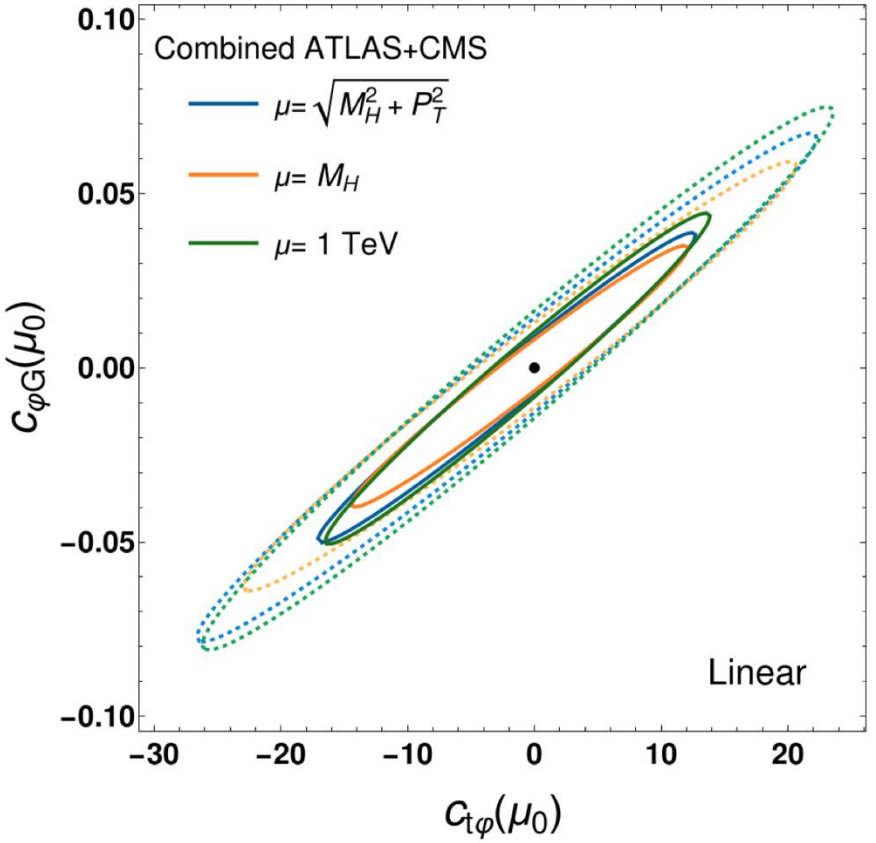






other 2D fits





Backup: more plots about mixing