Top EFT in MC: ttV and ttH at NLO in QCD

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Nikhef

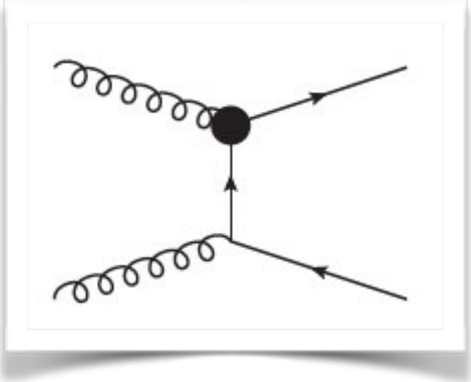
based on arXiv: 1601.08193 and 1607.05330

LHC TOP WG
CERN
23/11/16

SMEFT in processes with tops

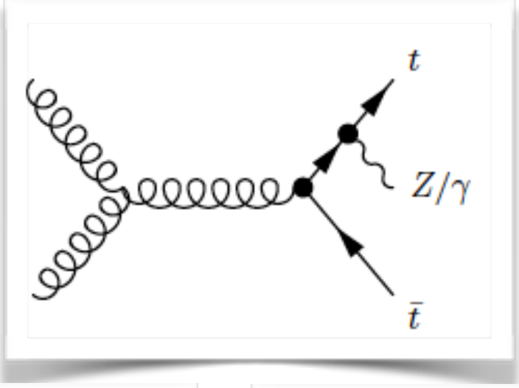
Rich phenomenology:

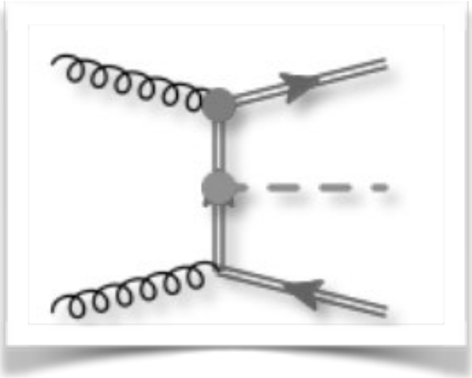
pair production



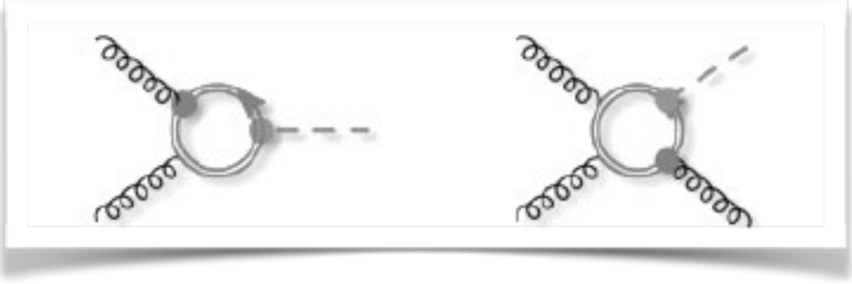
single

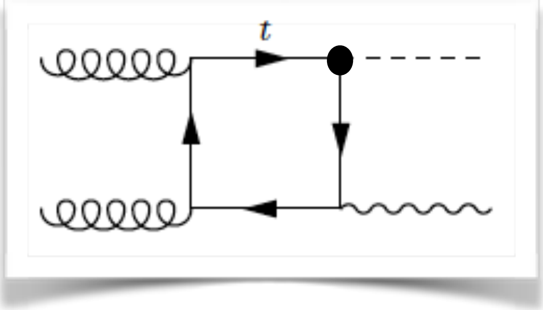
associated production

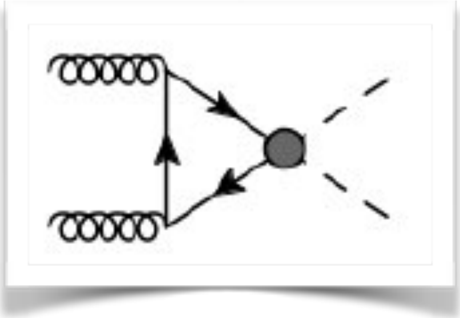




top loops







Top-quark operators and how to look for them

$$O_{\varphi Q}^{(3)} = i\frac{1}{2}y_t^2 \left(\varphi^\dagger \overleftrightarrow{D}^I_\mu \varphi\right)\left(\bar{Q}\gamma^\mu\tau^I Q\right)$$

$$O_{\varphi Q}^{(1)} = i\frac{1}{2}y_t^2 \left(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi\right)\left(\bar{Q}\gamma^\mu Q\right)$$

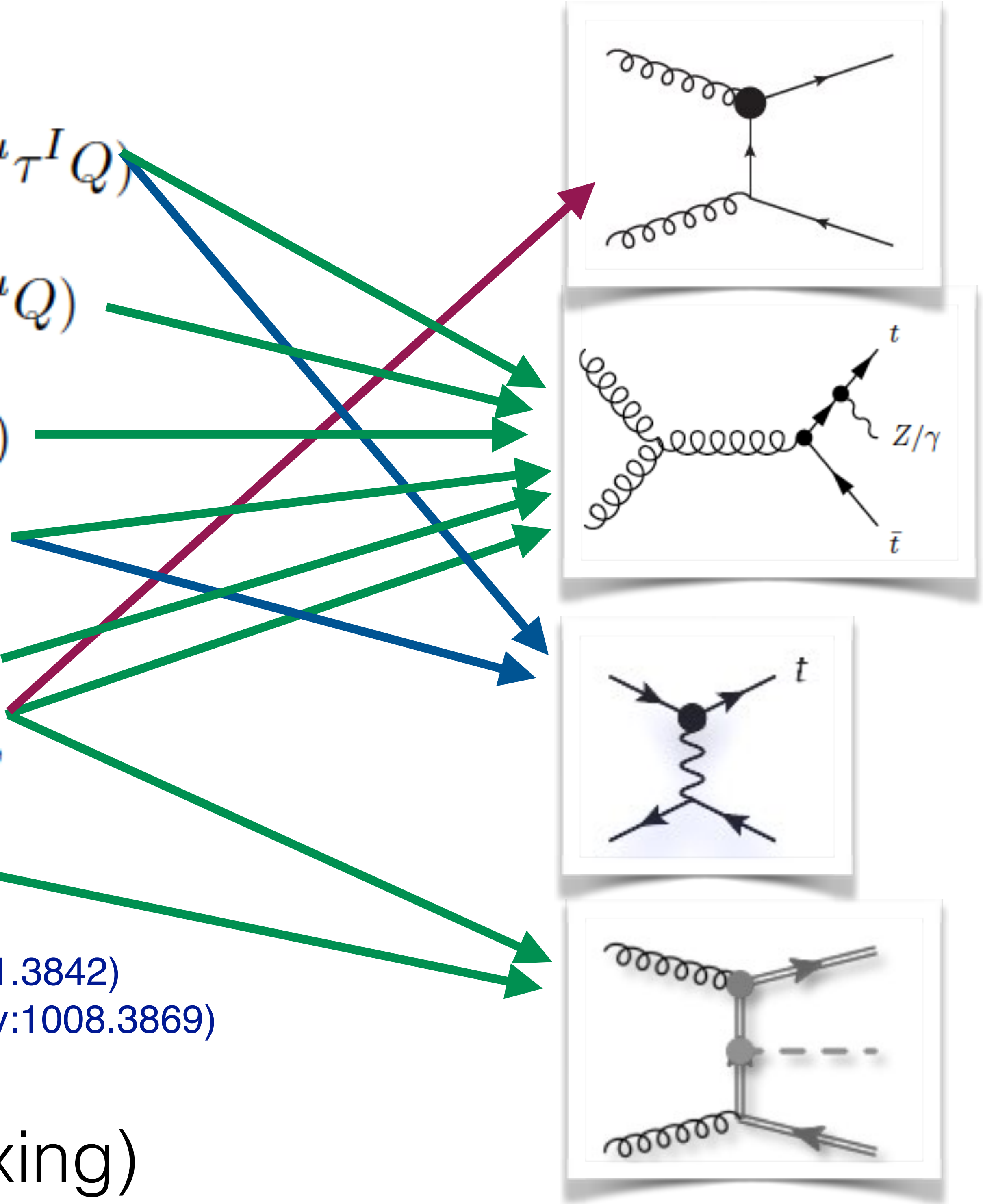
$$O_{\varphi t} = i\frac{1}{2}y_t^2 \left(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi\right)\left(\bar{t}\gamma^\mu t\right)$$

$$O_{tW} = y_t g_w (\bar{Q}\sigma^{\mu\nu}\tau^I t)\tilde{\varphi}W^I_{\mu\nu}$$

$$O_{tB} = y_t g_Y (\bar{Q}\sigma^{\mu\nu} t)\tilde{\varphi}B_{\mu\nu}$$

$$O_{tG} = y_t g_s (\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{\varphi}G^A_{\mu\nu}\,,$$

$$O_{t\phi} = y_t^3 \left(\phi^\dagger\phi\right)\left(\bar{Q}t\right)\tilde{\phi}$$



see for example: Aguilar-Saavedra (arXiv:0811.3842)
Zhang and Willenbrock (arXiv:1008.3869)

+four-fermion operators

+non-top operators (mixing)

Operators entering various processes: Global approach needed

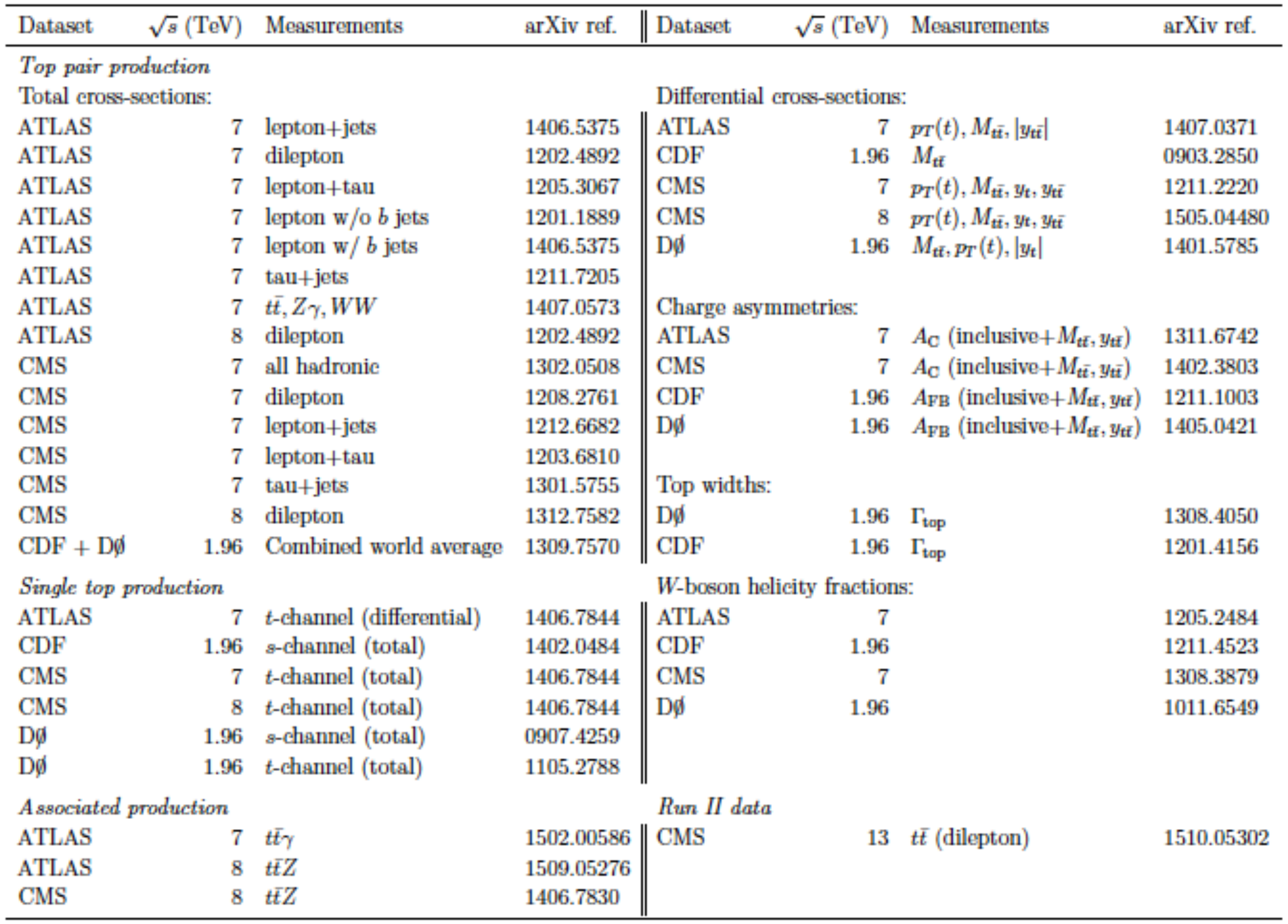
Towards global fits

EFT only makes sense if we follow a global approach

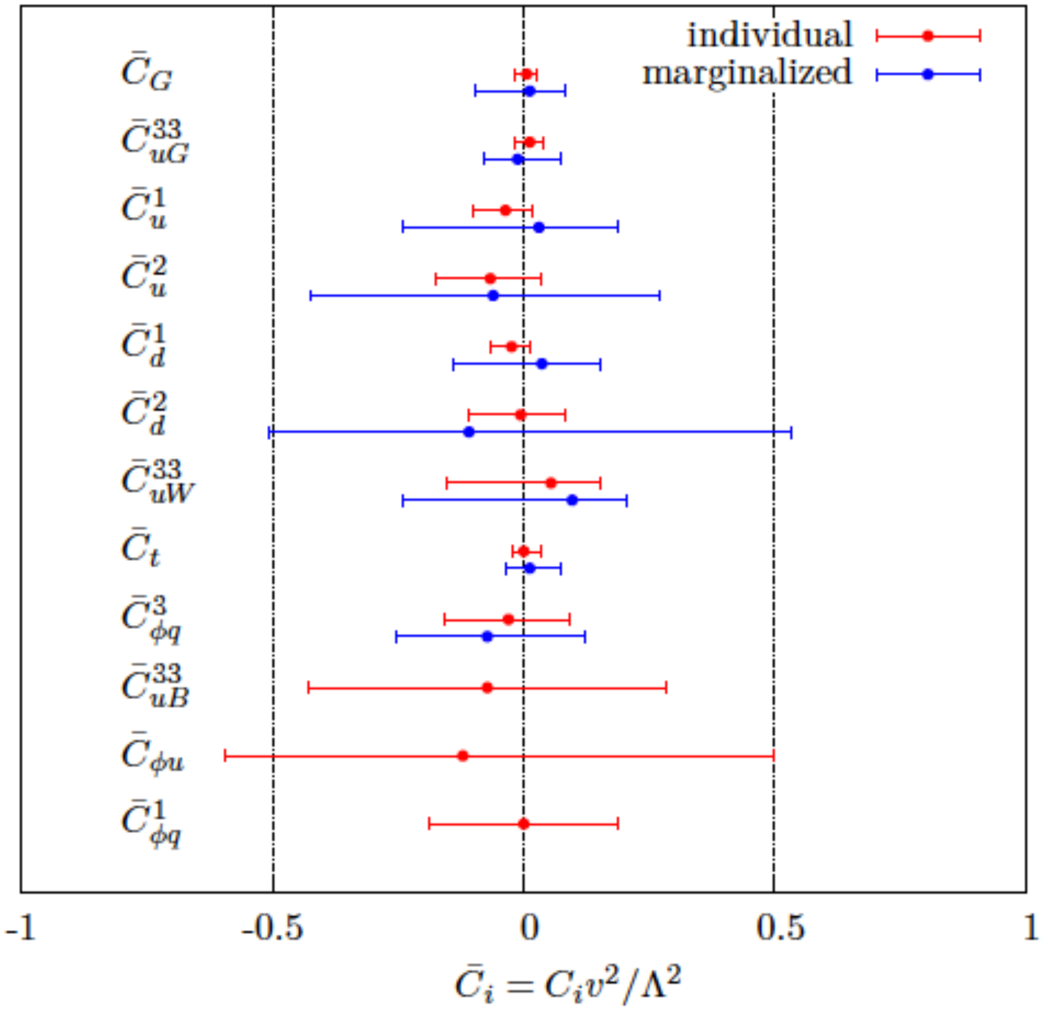
First work towards global fits:

Buckley et al arxiv:1506.08845 and 1512.03360

(N)NLO SM + LO EFT



Dataset	$\sqrt{s}$ (TeV)	Measurements	arXiv ref.	Dataset	$\sqrt{s}$ (TeV)	Measurements	arXiv ref.
Top pair production							
Total cross-sections:				Differential cross-sections:			
ATLAS	7	lepton+jets	1406.5375	ATLAS	7	$p_T(t)$, $M_{t\bar{t}}$, $\lvert y_{t\bar{t}}\rvert$	1407.0371
ATLAS	7	dilepton	1202.4892	CDF	1.96	$M_{t\bar{t}}$	0903.2850
ATLAS	7	lepton+tau	1205.3067	CMS	7	$p_T(t)$, $M_{t\bar{t}}$, y_t, $y_{t\bar{t}}$	1211.2220
ATLAS	7	lepton w/o b jets	1201.1889	CMS	8	$p_T(t)$, $M_{t\bar{t}}$, y_t, $y_{t\bar{t}}$	1505.04480
ATLAS	7	lepton w/ b jets	1406.5375	DØ	1.96	$M_{t\bar{t}}$, $p_T(t)$, $\lvert y_t\rvert$	1401.5785
ATLAS	7	tau+jets	1211.7205				
ATLAS	7	$t\bar{t}$, $Z\gamma$, WW	1407.0573	Charge asymmetries:			
ATLAS	8	dilepton	1202.4892	ATLAS	7	A_C (inclusive+$M_{t\bar{t}}$, $y_{t\bar{t}}$)	1311.6742
CMS	7	all hadronic	1302.0508	CMS	7	A_C (inclusive+$M_{t\bar{t}}$, $y_{t\bar{t}}$)	1402.3803
CMS	7	dilepton	1208.2761	CDF	1.96	A_{FB} (inclusive+$M_{t\bar{t}}$, $y_{t\bar{t}}$)	1211.1003
CMS	7	lepton+jets	1212.6682	DØ	1.96	A_{FB} (inclusive+$M_{t\bar{t}}$, $y_{t\bar{t}}$)	1405.0421
CMS	7	lepton+tau	1203.6810				
CMS	7	tau+jets	1301.5755	Top widths:			
CMS	8	dilepton	1312.7582	DØ	1.96	$\Gamma_{\rm top}$	1308.4050
CDF + DØ	1.96	Combined world average	1309.7570	CDF	1.96	$\Gamma_{\rm top}$	1201.4156
Single top production				*W*-boson helicity fractions:			
ATLAS	7	t-channel (differential)	1406.7844	ATLAS	7		1205.2484
CDF	1.96	s-channel (total)	1402.0484	CDF	1.96		1211.4523
CMS	7	t-channel (total)	1406.7844	CMS	7		1308.3879
CMS	8	t-channel (total)	1406.7844	DØ	1.96		1011.6549
DØ	1.96	s-channel (total)	0907.4259				
DØ	1.96	t-channel (total)	1105.2788				
Associated production				*Run II data*			
ATLAS	7	$t\bar{t}\gamma$	1502.00586	CMS	13	$t\bar{t}$ (dilepton)	1510.05302
ATLAS	8	$t\bar{t}Z$	1509.05276				
CMS	8	$t\bar{t}Z$	1406.7830				



Tevatron and LHC data

Cross-sections and distributions

The need for NLO

Impact of NLO corrections in the light of global fits:

- Accuracy and precision: NLO corrections modify the central value and come with reduced theoretical uncertainties compared to LO
- Impact on the distributions - non-flat K-factors different between operators and different from the SM
- Better control on RG and operator mixing effects - new operators entering at NLO
- Effort to match SM precision in the light of more sensitive measurements and in the context of global EFT fits where precision is needed to extract maximal information on the coefficients

SMEFT@NLO

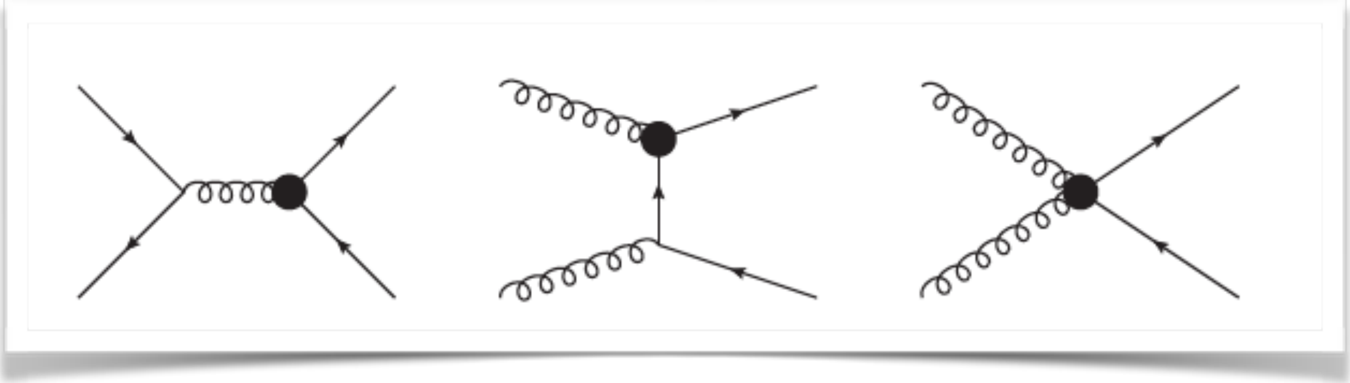
- SMEFT@NLO ingredients:
  - Mixing between operators: anomalous dimension matrix: Alonso et al. arxiv:1312.2014
  - Additional operators at NLO

Automation within MadGraph5_aMC@NLO
R2+UV counterterms for the NLO computation:
NLOCT Degrande (arxiv:1406.3030)

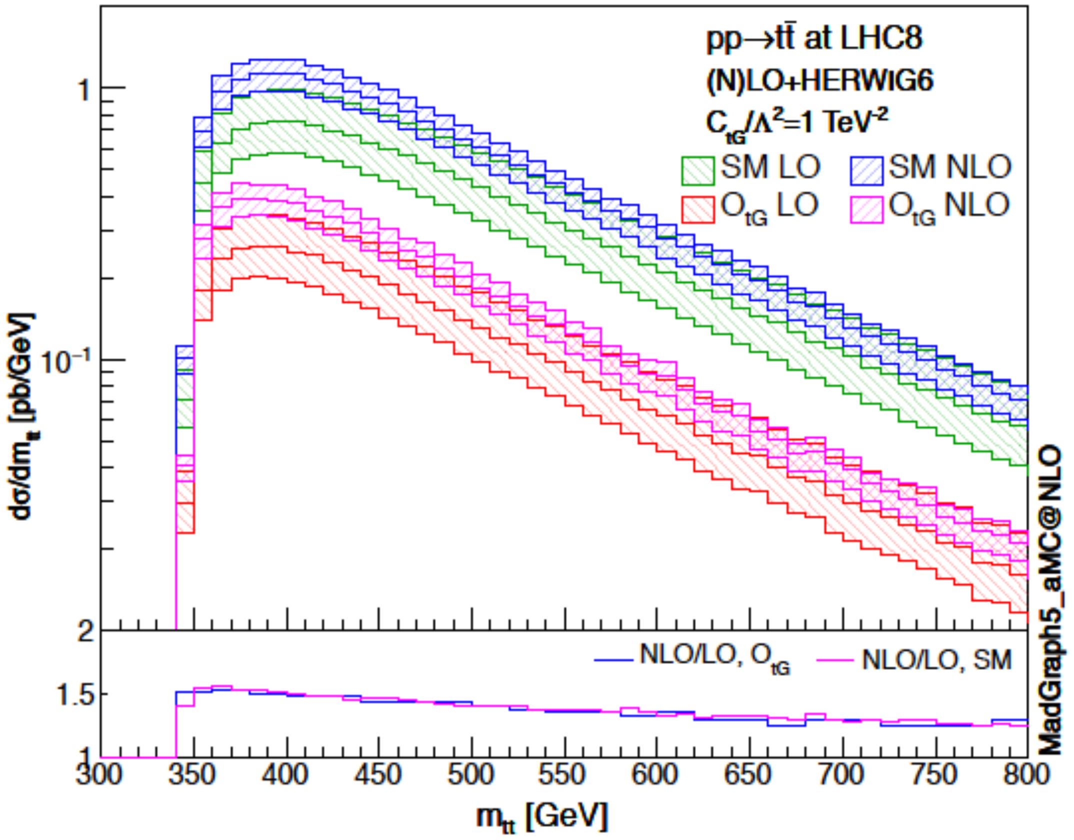
Progress in top quark processes in this framework:

- top pair production: Franzosi and Zhang (arxiv:1503.08841)
- single top production: C. Zhang (arxiv:1601.06163)
- ttZ/γ: O. Bylund, F. Maltoni, I. Tsinikos, EV, C. Zhang (arXiv:1601.08193)
- ttH: F. Maltoni, EV, C. Zhang (arXiv:1607.05330)
- FCNC Degrande et al (arXiv:1412.5594),Durieux et al (arXiv:1412.7166)

First example: top-pair production

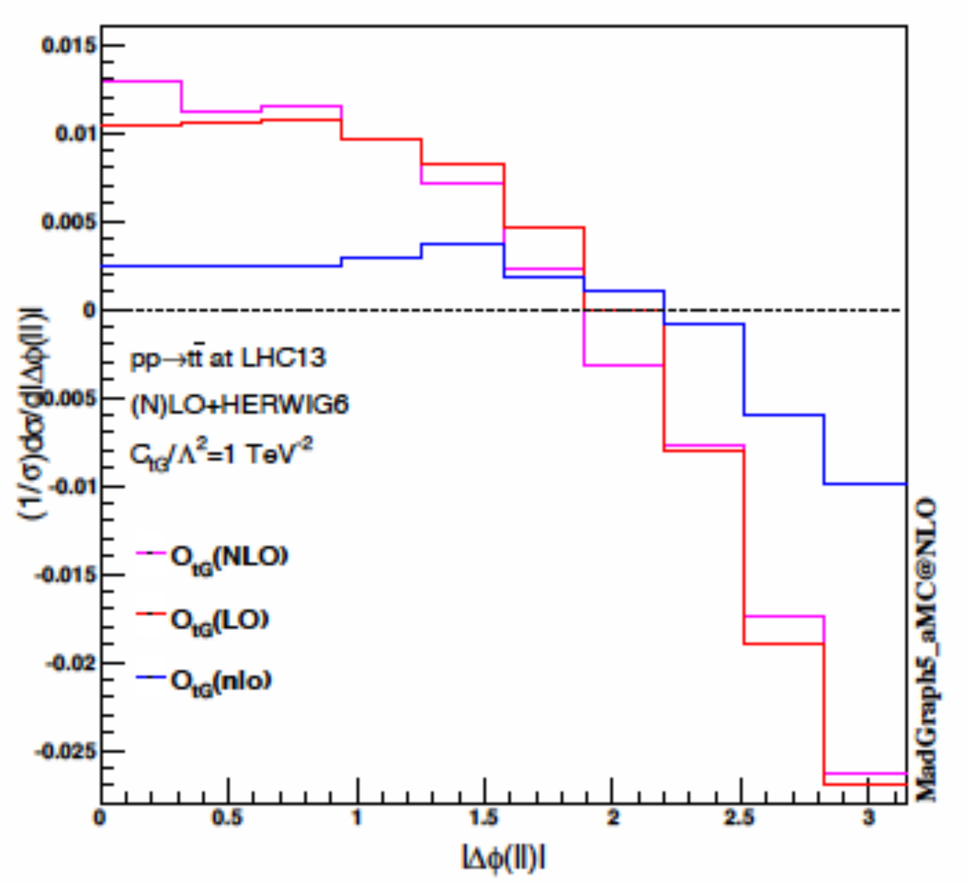


$$O_{tG} = y_t g_s \left(\bar{Q}\sigma^{\mu\nu}T^A t\right)\tilde{\phi}G^A_{\mu\nu}$$

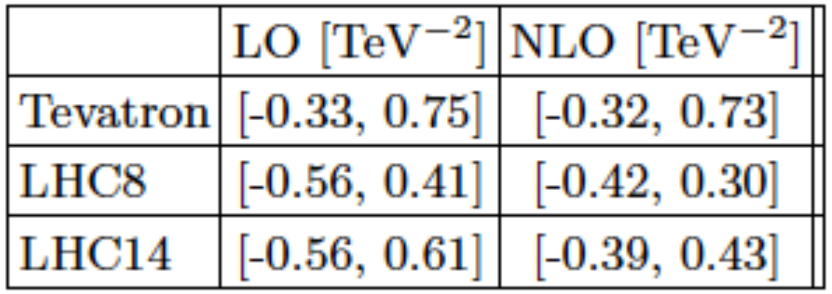


Zhang and Franzosi arXiv:1503.08841

4-fermion NLO implementation:
in progress Degrande et al



Limits on c_{tG}/Λ^2 using total
cross section



	LO [TeV^{-2}]	NLO [TeV^{-2}]
Tevatron	[-0.33, 0.75]	[-0.32, 0.73]
LHC8	[-0.56, 0.41]	[-0.42, 0.30]
LHC14	[-0.56, 0.61]	[-0.39, 0.43]

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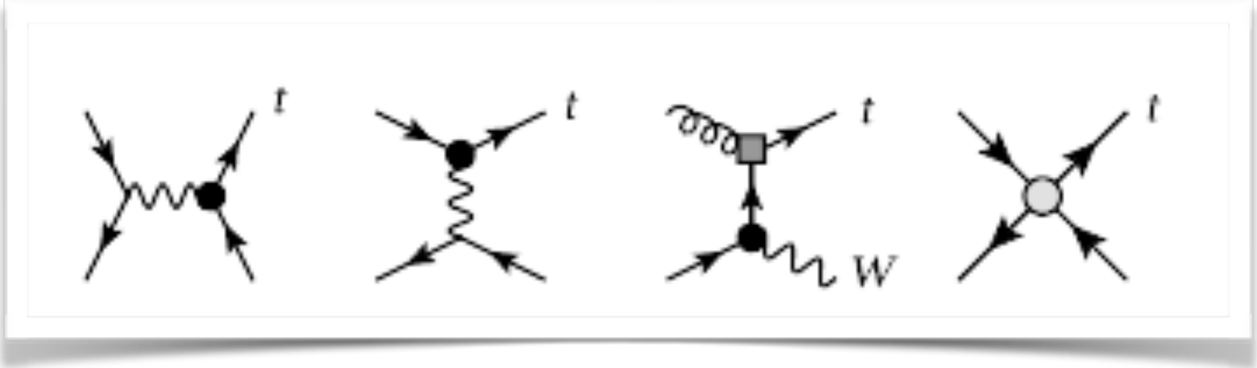
single top production

$$O_{\varphi Q}^{(3)} = i\frac{1}{2}y_t^2\left(\varphi^\dagger \overleftrightarrow{D}_\mu^I \varphi\right)(\bar{Q}\gamma^\mu \tau^I Q)$$

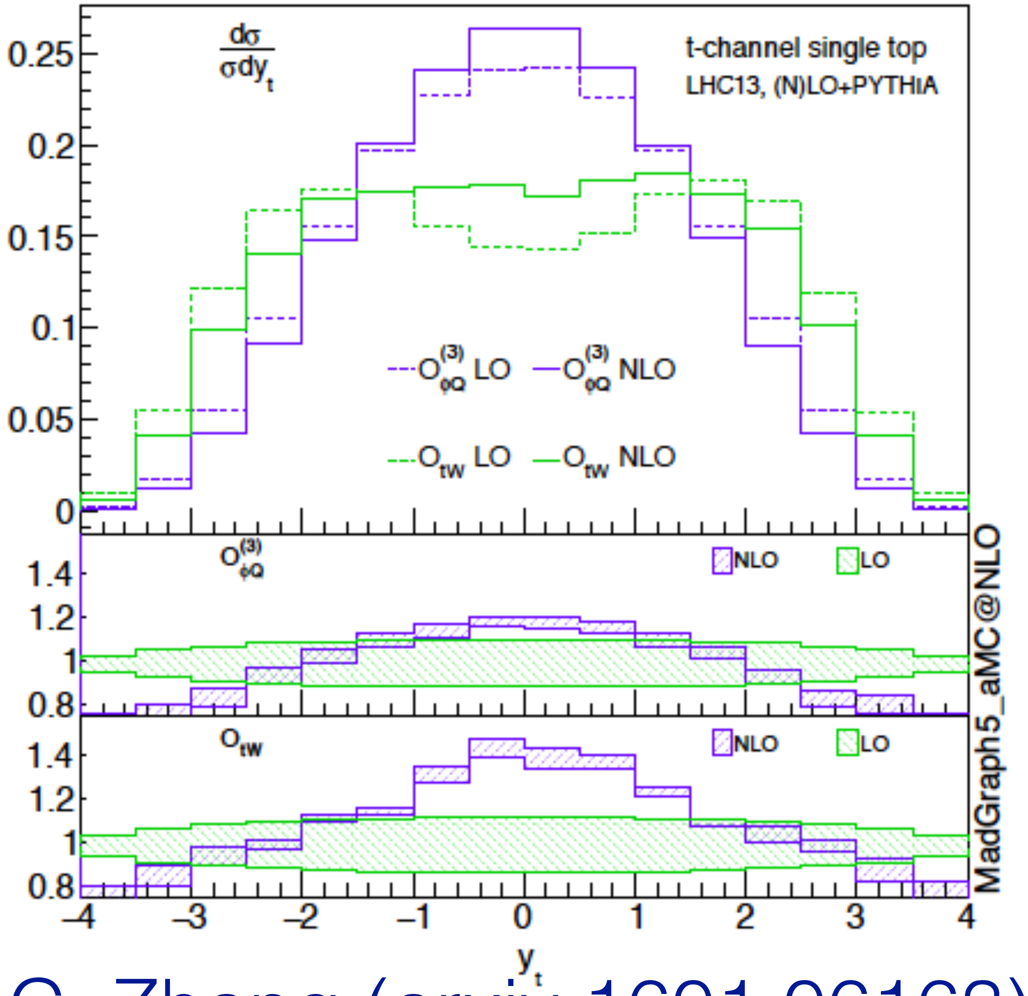
$$O_{tW} = y_t g_W(\bar{Q}\sigma^{\mu\nu}\tau^I t)\tilde{\varphi}W_{\mu\nu}^I$$

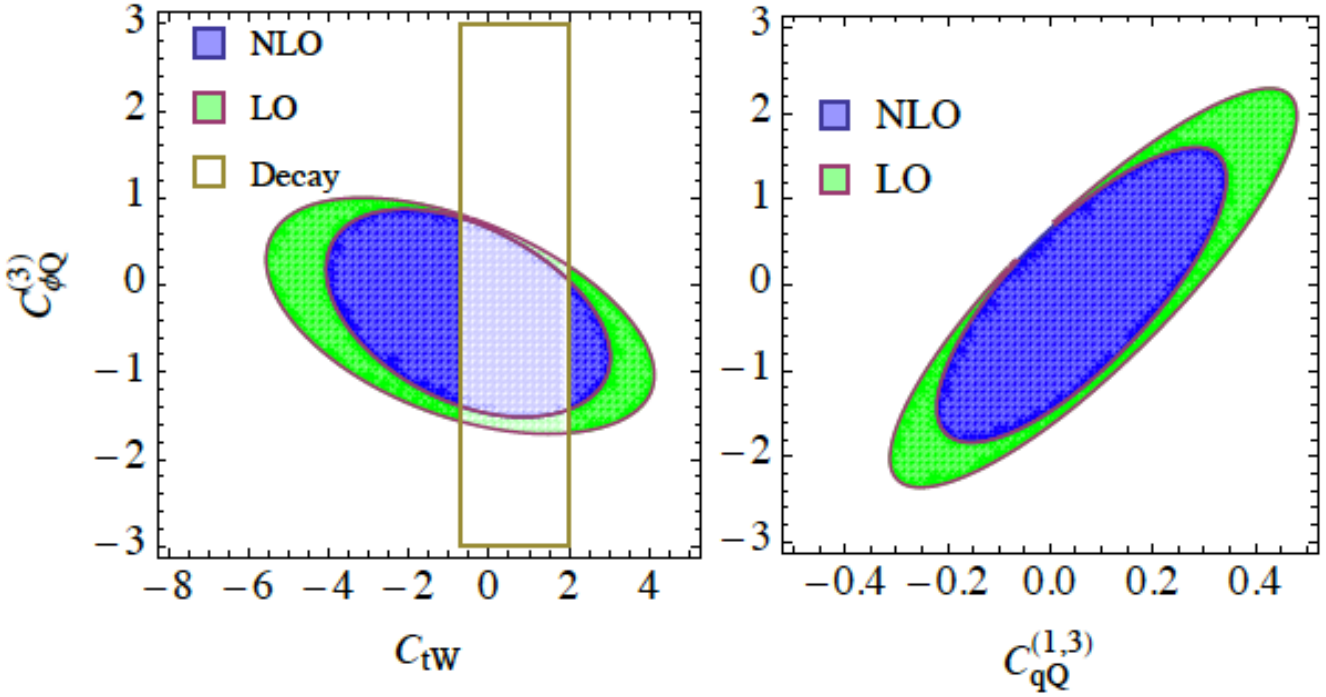
$$O_{tG} = y_t g_s(\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{\varphi}G_{\mu\nu}^A$$

$$O_{qQ,rs}^{(3)} = (\bar{q}_r\gamma_\mu\tau^I q_s)(\bar{Q}\gamma^\mu\tau^I Q)$$



Only one four-fermion contributing





C. Zhang (arxiv:1601.06163)

NLO corrections:

- Impact on distributions
- Impact on limits
  - Accuracy+precision

Top-pair+Z/γ

13TeV	$\mathcal{O}_{tG}$	$\mathcal{O}_{\phi Q}^{(3)}$	$\mathcal{O}_{\phi t}$	$\mathcal{O}_{tW}$
$\sigma_{i,LO}^{(1)}$	$286.7^{+38.2\%}_{-25.5\%}$	$78.3^{+40.4\%}_{-26.6\%}$	$51.6^{+40.1\%}_{-26.4\%}$	$-0.20(3)^{+88.0\%}_{-230.0\%}$
$\sigma_{i,NLO}^{(1)}$	$310.5^{+5.4\%}_{-9.7\%}$	$90.6^{+7.1\%}_{-11.0\%}$	$57.5^{+5.8\%}_{-10.3\%}$	$-1.7(2)^{+31.3\%}_{-49.1\%}$
K-factor	1.08	1.16	1.11	8.5
$\sigma_{ii,LO}^{(2)}$	$258.5^{+49.7\%}_{-30.4\%}$	$2.8(1)^{+39.7\%}_{-26.9\%}$	$2.9(1)^{+39.7\%}_{-26.7\%}$	$20.9^{+44.3\%}_{-28.3\%}$
$\sigma_{ii,NLO}^{(2)}$	$244.5^{+4.2\%}_{-8.1\%}$	$3.8(3)^{+13.2\%}_{-14.4\%}$	$3.9(3)^{+13.8\%}_{-14.6\%}$	$24.2^{+6.2\%}_{-11.2\%}$

$$\sigma = \sigma_{SM} + \sum_i \frac{C_i}{(\Lambda/1\text{TeV})^2}\sigma_i^{(1)} + \sum_{i\leq j}\frac{C_iC_j}{(\Lambda/1\text{TeV})^4}\sigma_{ij}^{(2)}$$

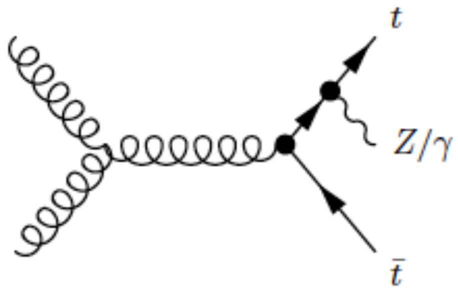
Small contribution from O_{tW} and O_{tB} at $O(1/\Lambda^2)$ but large at $O(1/\Lambda^4)$

How should we treat $O(1/\Lambda^4)$ terms?

$$C_i^2\frac{E^4}{\Lambda^4} > C_i\frac{E^2}{\Lambda^2} > \boxed{1 > \frac{E^2}{\Lambda^2}}$$

EFT condition satisfied

To be checked on a case-by-case basis



$$O_{\varphi Q}^{(3)} = i\frac{1}{2}y_t^2\left(\varphi^\dagger \overleftrightarrow{D}^I_\mu\varphi\right)(\bar{Q}\gamma^\mu\tau^I Q)$$

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$$O_{\varphi t} = i\frac{1}{2}y_t^2\left(\varphi^\dagger \overleftrightarrow{D}_\mu\varphi\right)(\bar{t}\gamma^\mu t)$$

$$O_{tW} = y_t g_w(\bar{Q}\sigma^{\mu\nu}\tau^I t)\tilde{\varphi}W^I_{\mu\nu}$$

$$O_{tB} = y_t g_Y(\bar{Q}\sigma^{\mu\nu}t)\tilde{\varphi}B_{\mu\nu}$$

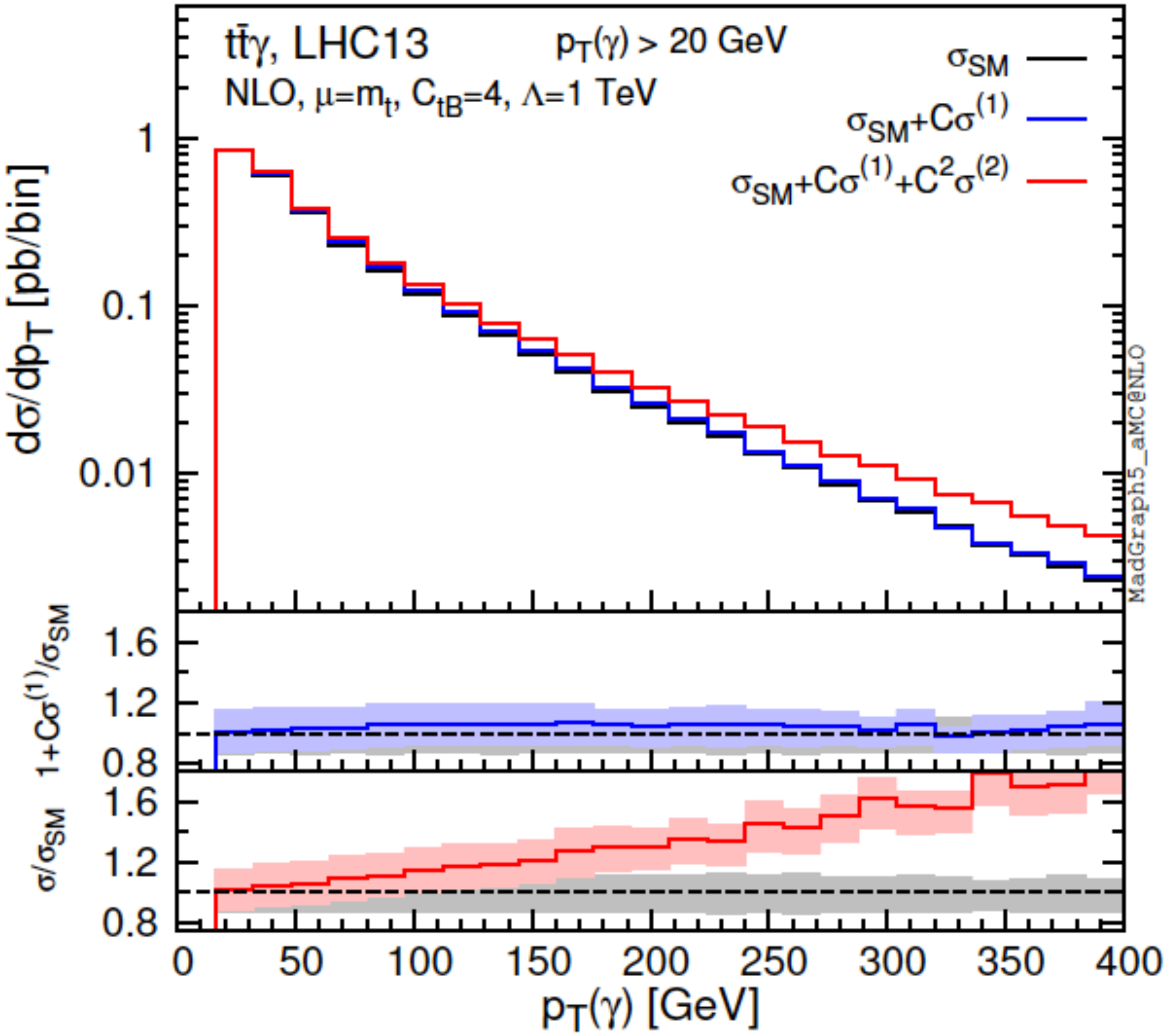
$$O_{tG} = y_t g_s(\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{\varphi}G^A_{\mu\nu}\,,$$

Anomalous dimension matrix: O_{tW}, O_{tB}, O_{tG}

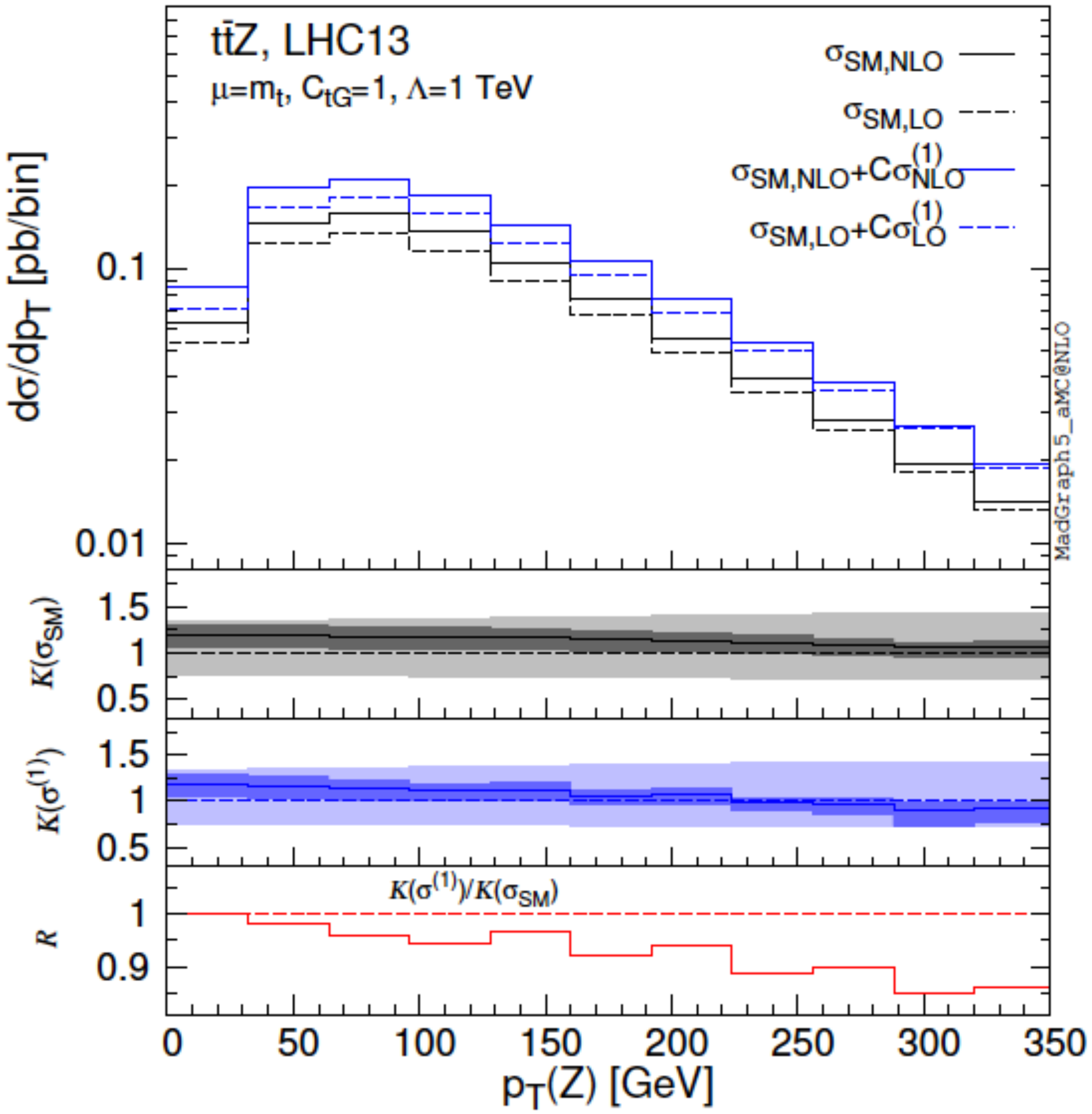
$$\gamma = \frac{2\alpha_s}{\pi}\begin{pmatrix} \frac{1}{6} & 0 & 0 \\ \frac{1}{3} & \frac{1}{3} & 0 \\ \frac{5}{9} & 0 & \frac{1}{3} \end{pmatrix}$$

Bylund et al arXiv:1601.08193

Differential distributions for tt+V



Large contribution at O(1/Λ⁴) rising with energy



Using SM k-factors is not enough

arXiv:1601.08193

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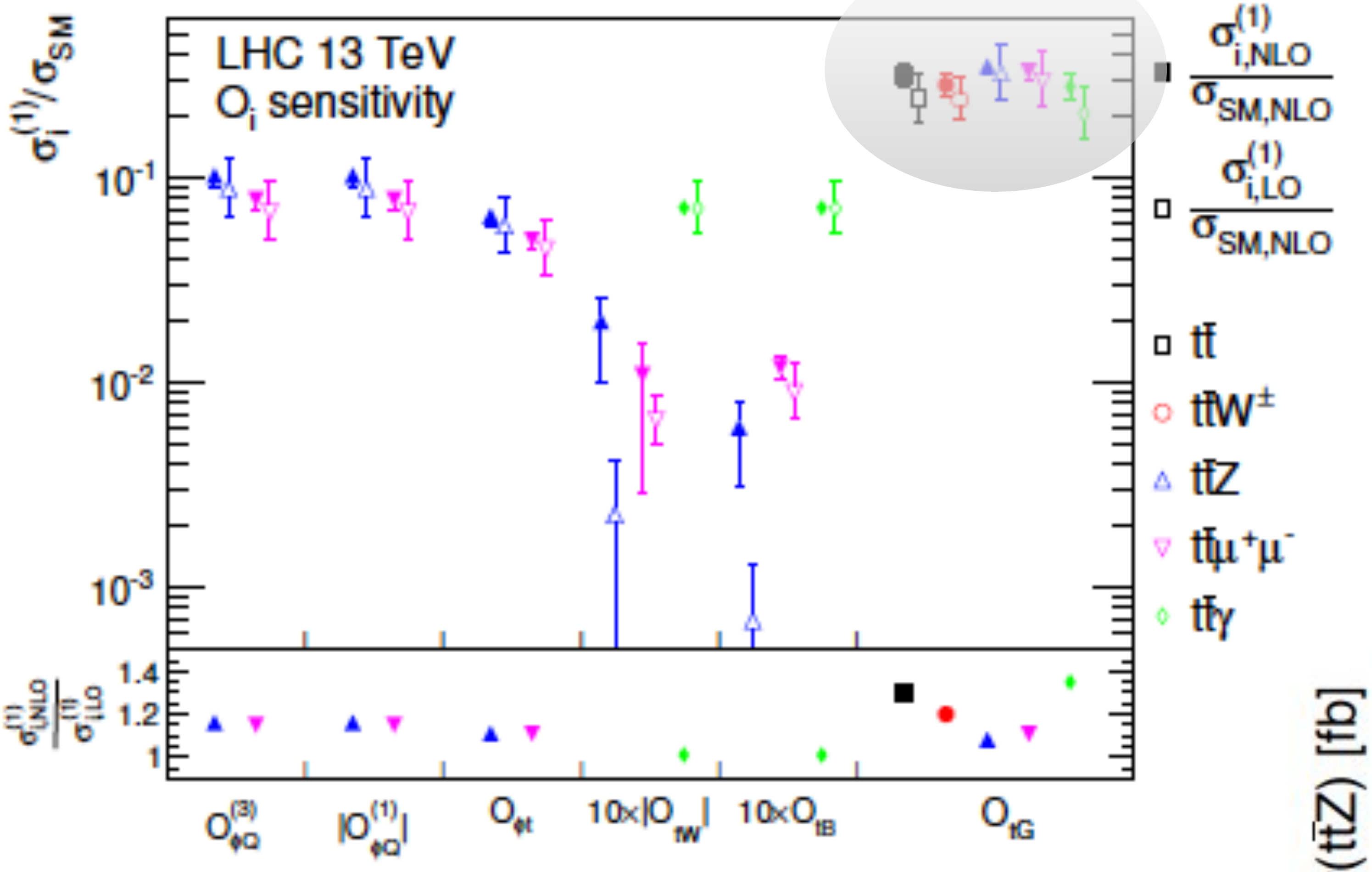
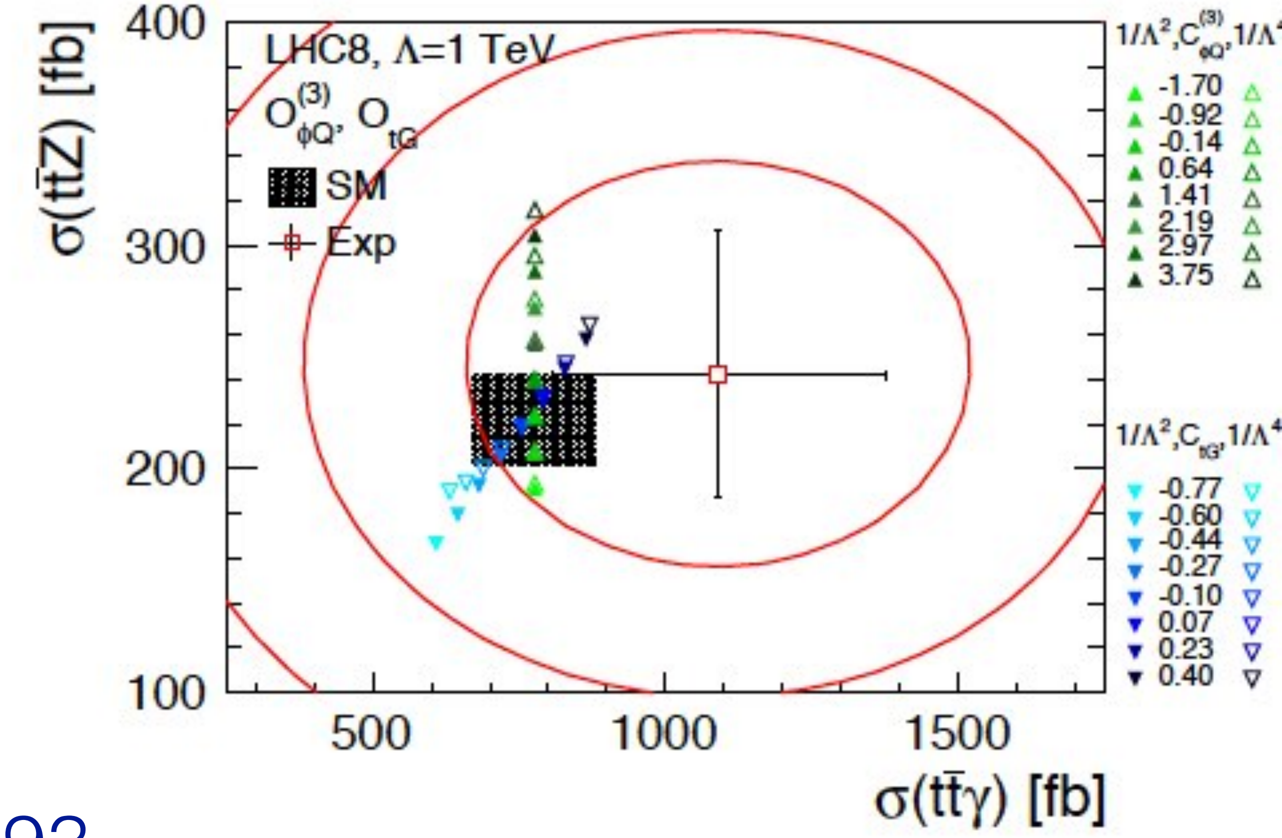
A sensitivity study



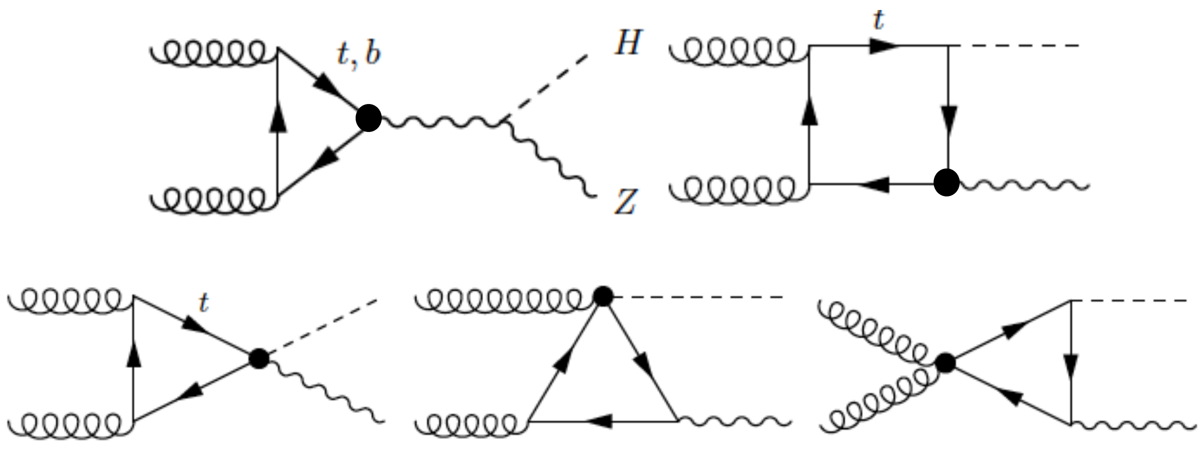
Chromomagnetic operator affecting all processes in the same way



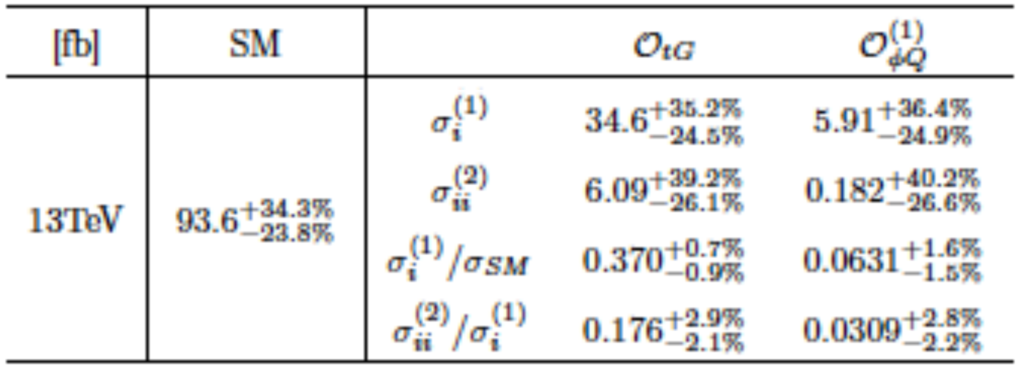
LHC measurements of ttV processes can set constraints on the Wilson coefficients
See also: Schulze et al. arXiv:1404.1005, 1501.05939, 1603.08911 in the anomalous coupling framework

arXiv:1601.08193

Top-operators in non-top final states

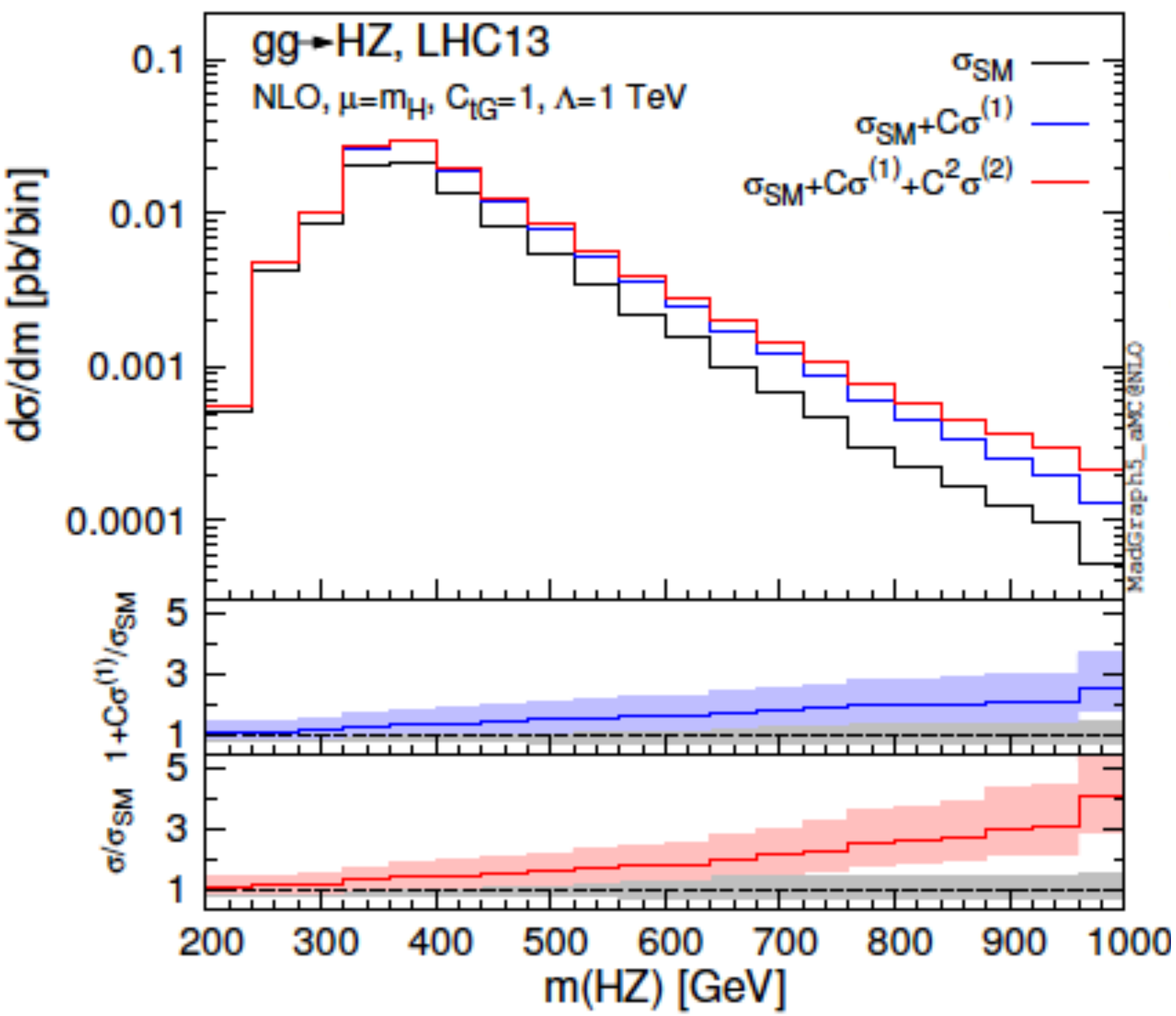


Gluon-fusion contribution to HZ production affected by the operators changing gtt, ttZ and ttH → Additional information



[fb]	SM		$\mathcal{O}_{tG}$	$\mathcal{O}_{\phi Q}^{(1)}$
13TeV	$93.6^{+34.3\%}_{-23.8\%}$	$\sigma_{i}^{(1)}$	$34.6^{+35.2\%}_{-24.5\%}$	$5.91^{+36.4\%}_{-24.9\%}$
		$\sigma_{ii}^{(2)}$	$6.09^{+39.2\%}_{-26.1\%}$	$0.182^{+40.2\%}_{-26.6\%}$
		$\sigma_{i}^{(1)}/\sigma_{SM}$	$0.370^{+0.7\%}_{-0.9\%}$	$0.0631^{+1.6\%}_{-1.5\%}$
		$\sigma_{ii}^{(2)}/\sigma_{i}^{(1)}$	$0.176^{+2.9\%}_{-2.1\%}$	$0.0309^{+2.8\%}_{-2.2\%}$

No contributions from the electroweak dipole operators due to charge conjugation invariance



See also:
Englert et al arXiv:1603.05304

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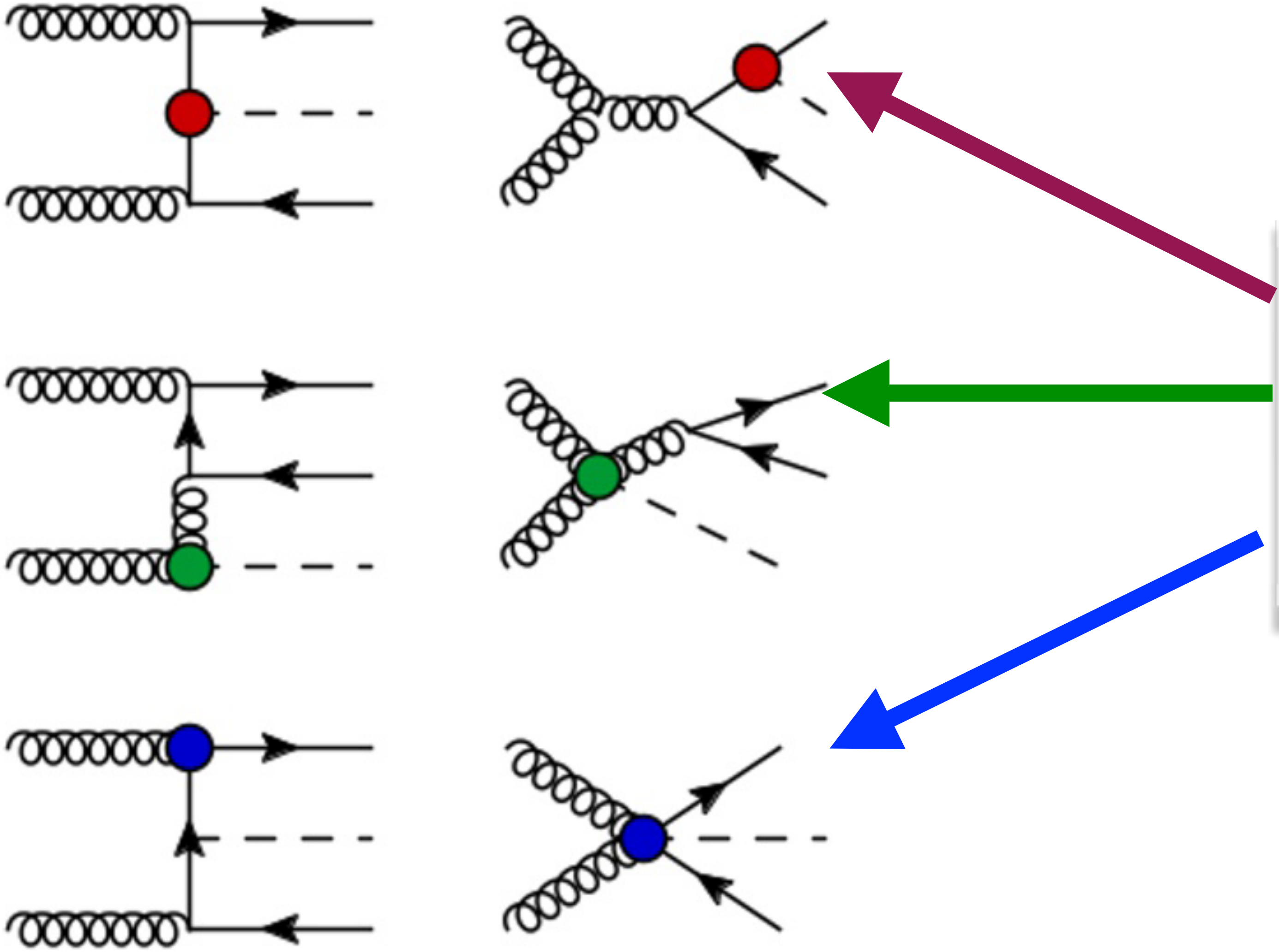
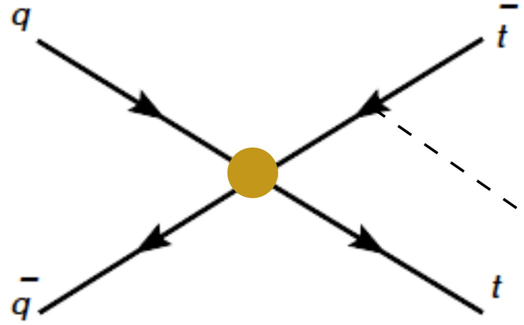
ttH in the EFT

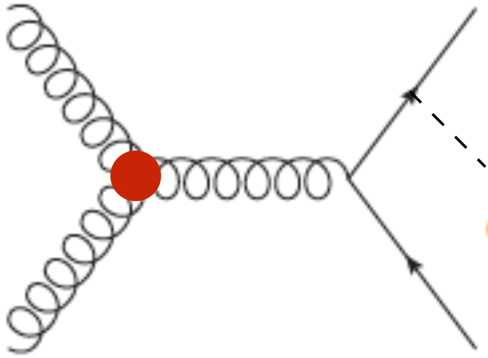


$$O_{t\phi} = y_t^3 \left(\phi^\dagger\phi\right) \left(\bar{Q}t\right) \tilde{\phi}$$
$$O_{\phi G} = y_t^2 \left(\phi^\dagger\phi\right) G^A_{\mu\nu} G^{A\mu\nu}$$
$$O_{tG} = y_t g_s (\bar{Q}\sigma^{\mu\nu} T^A t)\tilde{\phi} G^A_{\mu\nu}$$

At NLO in this talk



4-fermion operators



$$O_G = g_s f^{ABC} G^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$$

Not in this talk, work in progress

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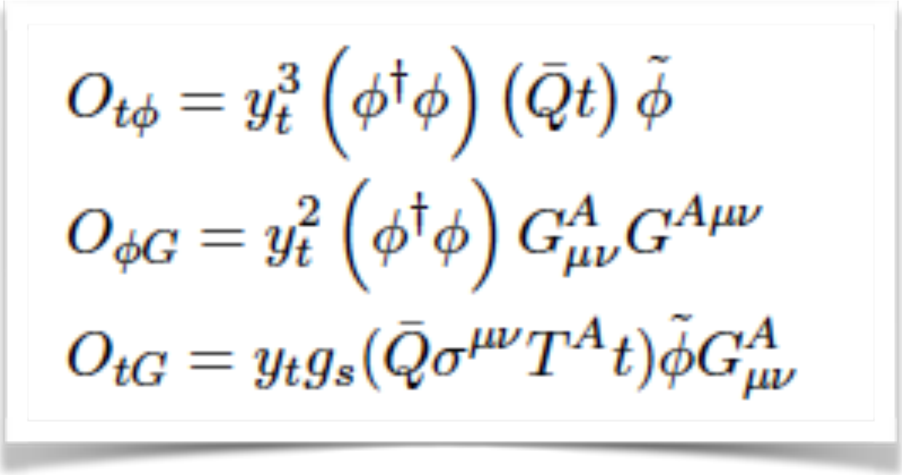
ttH@NLO



$$O_{t\phi} = y_t^3 \left(\phi^\dagger \phi\right) \left(\bar{Q} t\right) \tilde{\phi}$$

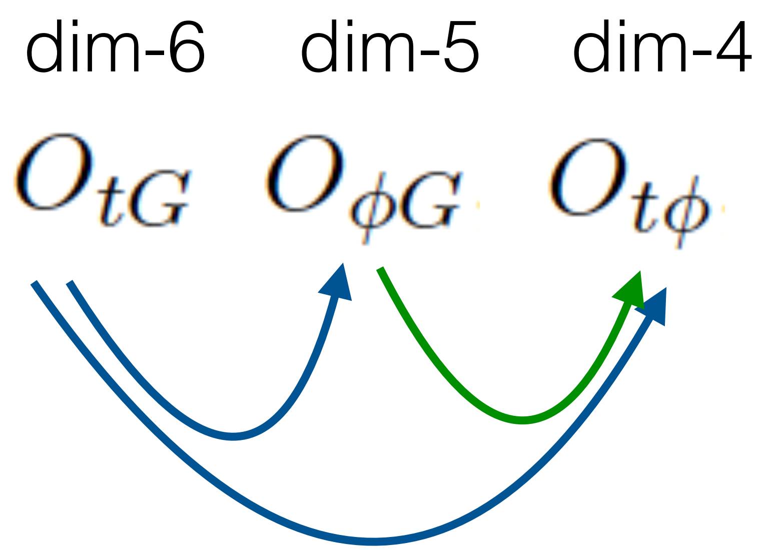
$$O_{\phi G} = y_t^2 \left(\phi^\dagger \phi\right) G^A_{\mu\nu} G^{A\mu\nu}$$

$$O_{tG} = y_t g_s (\bar{Q} \sigma^{\mu\nu} T^A t) \tilde{\phi} G^A_{\mu\nu}$$

$$(O_{t\phi}, O_{\phi G}, O_{tG})$$

$$\frac{dC_i(\mu)}{d\log\mu} = \frac{\alpha_s}{\pi} \gamma_{ij} C_j(\mu) \qquad \gamma = \begin{pmatrix} -2 & 16 & 8 \\ 0 & -7/2 & 1/2 \\ 0 & 0 & 1/3 \end{pmatrix}$$

Alonso et al. arxiv:1312.2014



Higher-dimension operators mix into lower-dimension ones

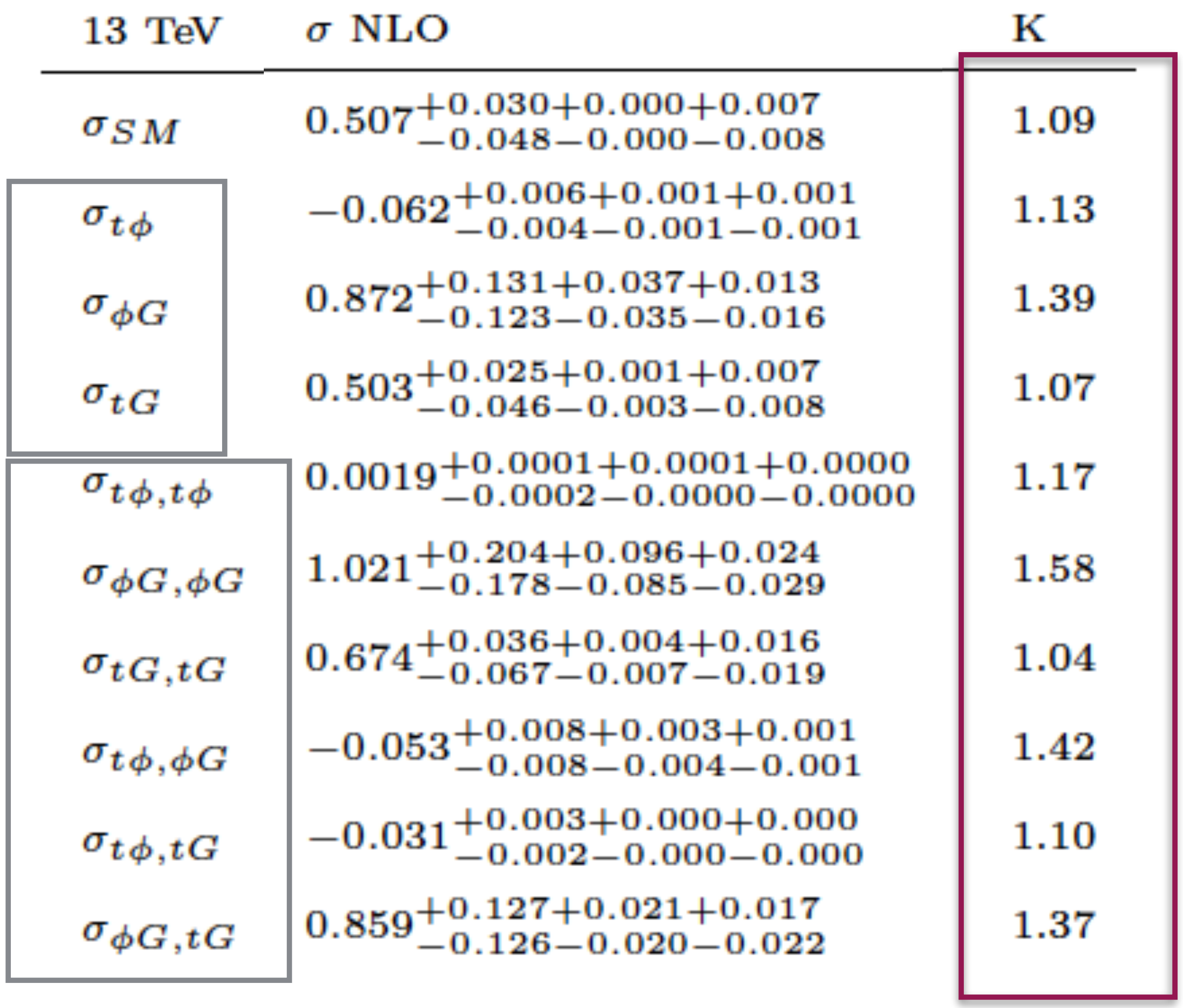
Setup allows computation of:

$$\sigma = \sigma_{\mathrm{SM}} + \sum_i \frac{1\mathrm{TeV}^2}{\Lambda^2} C_i \sigma_i + \sum_{i \leq j} \frac{1\mathrm{TeV}^4}{\Lambda^4} C_i C_j \sigma_{ij}.$$

interference with SM

interference between operators, squared contributions

Cross-section results (1)



13 TeV	σ NLO	K
σ_{SM}	$0.507^{+0.030+0.000+0.007}_{-0.048-0.000-0.008}$	1.09
$\sigma_{t\phi}$	$-0.062^{+0.006+0.001+0.001}_{-0.004-0.001-0.001}$	1.13
$\sigma_{\phi G}$	$0.872^{+0.131+0.037+0.013}_{-0.123-0.035-0.016}$	1.39
σ_{tG}	$0.503^{+0.025+0.001+0.007}_{-0.046-0.003-0.008}$	1.07
$\sigma_{t\phi,t\phi}$	$0.0019^{+0.0001+0.0001+0.0000}_{-0.0002-0.0000-0.0000}$	1.17
$\sigma_{\phi G,\phi G}$	$1.021^{+0.204+0.096+0.024}_{-0.178-0.085-0.029}$	1.58
$\sigma_{tG,tG}$	$0.674^{+0.036+0.004+0.016}_{-0.067-0.007-0.019}$	1.04
$\sigma_{t\phi,\phi G}$	$-0.053^{+0.008+0.003+0.001}_{-0.008-0.004-0.001}$	1.42
$\sigma_{t\phi,tG}$	$-0.031^{+0.003+0.000+0.000}_{-0.002-0.000-0.000}$	1.10
$\sigma_{\phi G,tG}$	$0.859^{+0.127+0.021+0.017}_{-0.126-0.020-0.022}$	1.37

$$\sigma = \sigma_{\rm SM} + \sum_i \frac{1{\rm TeV}^2}{\Lambda^2} C_i \sigma_i + \sum_{i \leq j} \frac{1{\rm TeV}^4}{\Lambda^4} C_i C_j \sigma_{ij}.$$

- Different K-factors for different operators, different from the SM
- Large $1/\Lambda^4$ contribution for the chromomagnetic operator
- Constraints from top pair production: c_{tG}=[-0.42,0.30] Franzosi and Zhang arxiv:1503.08841
- Global approach needed to consistently extract information on coefficients within the SMEFT framework

Cross-section results (2)

13 TeV	σ NLO	$\sigma/\sigma_{\rm SM}$ NLO	K
$\sigma_{\rm SM}$	$0.507^{+0.030+0.000+0.007}_{-0.048-0.000-0.008}$	$1.000^{+0.000+0.000+0.000}_{-0.000-0.000-0.000}$	1.09
$\sigma_{t\phi}$	$-0.062\boxed{^{+0.006+0.001+0.001}_{-0.004-0.001-0.001}}$	$-0.123^{+0.001+0.001+0.000}_{-0.001-0.002-0.000}$	1.13
$\sigma_{\phi G}$	$0.872^{+0.131+0.037+0.013}_{-0.123-0.035-0.016}$	$1.722^{+0.146+0.073+0.004}_{-0.089-0.068-0.005}$	1.39
σ_{tG}	$0.503^{+0.025+0.001+0.007}_{-0.046-0.003-0.008}$	$0.991^{+0.004+0.003+0.000}_{-0.010-0.006-0.001}$	1.07
$\sigma_{t\phi,t\phi}$	$0.0019^{+0.0001+0.0001+0.0000}_{-0.0002-0.0000-0.0000}$	$0.0037^{+0.0001+0.0002+0.0000}_{-0.0000-0.0001-0.0000}$	1.17
$\sigma_{\phi G,\phi G}$	$1.021^{+0.204+0.096+0.024}_{-0.178-0.085-0.029}$	$2.016^{+0.267+0.190+0.021}_{-0.178-0.167-0.027}$	1.58
$\sigma_{tG,tG}$	$0.674^{+0.036+0.004+0.016}_{-0.067-0.007-0.019}$	$1.328^{+0.011+0.008+0.014}_{-0.038-0.014-0.018}$	1.04
$\sigma_{t\phi,\phi G}$	$-0.053^{+0.008+0.003+0.001}_{-0.008-0.004-0.001}$	$-0.105^{+0.006+0.006+0.000}_{-0.009-0.007-0.000}$	1.42
$\sigma_{t\phi,tG}$	$-0.031^{+0.003+0.000+0.000}_{-0.002-0.000-0.000}$	$-0.061^{+0.000+0.000+0.000}_{-0.000-0.001-0.000}$	1.10
$\sigma_{\phi G,tG}$	$0.859^{+0.127+0.021+0.017}_{-0.126-0.020-0.022}$	$1.691^{+0.137+0.042+0.013}_{-0.097-0.039-0.017}$	1.37

First systematic study of uncertainties:

- 1) Scale and PDF uncertainties:

Similar to SM

- Reduced scale and PDF uncertainties in the ratio over the SM
- 2) EFT scale uncertainties

$$\sigma_i(\mu_0;\mu) = \Gamma_{ji}(\mu,\mu_0)\sigma_j(\mu)\,.$$

$$\sigma_{ij}(\mu_0;\mu) = \Gamma_{ki}(\mu,\mu_0)\Gamma_{lj}(\mu,\mu_0)\sigma_{kl}(\mu)$$

$$\Gamma_{ij}(\mu,\mu_0) = \exp\left(\frac{-2}{\beta_0}\log\frac{\alpha_s(\mu)}{\alpha_s(\mu_0)}\gamma_{ij}\right)$$

Cross-sections evaluated at a different scale ($\mu_0/2$, $2\mu_0$) evolved back to μ_0 taking into account operator mixing and running

3) C/Λ^2 expansion

$$\sigma = \sigma_{\rm SM} + \sum_i \frac{C_i^{\rm dim6}}{(\Lambda/1{\rm TeV})^2}\sigma_i^{\rm (dim6)} + \boxed{\sum_{i\le j}\frac{C_i^{\rm dim6}C_j^{\rm dim6}}{(\Lambda/1{\rm TeV})^4}\sigma_{ij}^{\rm (dim6)}}$$

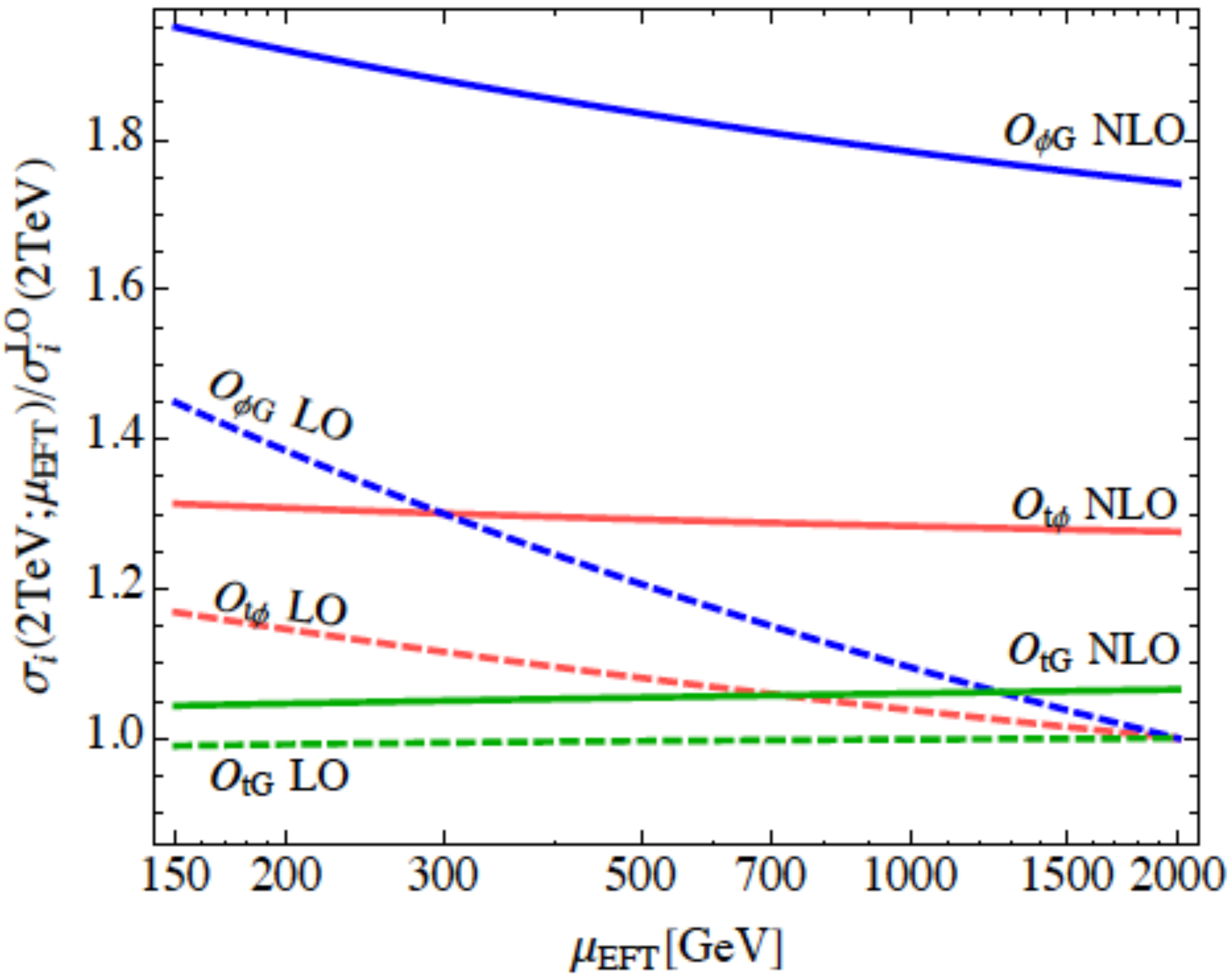
Included

$$\boxed{+\sum_i \frac{C_i^{\rm dim8}}{(\Lambda/1{\rm TeV})^4}\sigma_i^{\rm (dim8)}} + \mathcal{O}(\Lambda^{-6})\,.$$

Needs dim-8 operators (Not included here)
But it can be estimated using a cut-off
Contino et al arXiv:1604.0644

E.Vryonidou

A study of RG effects

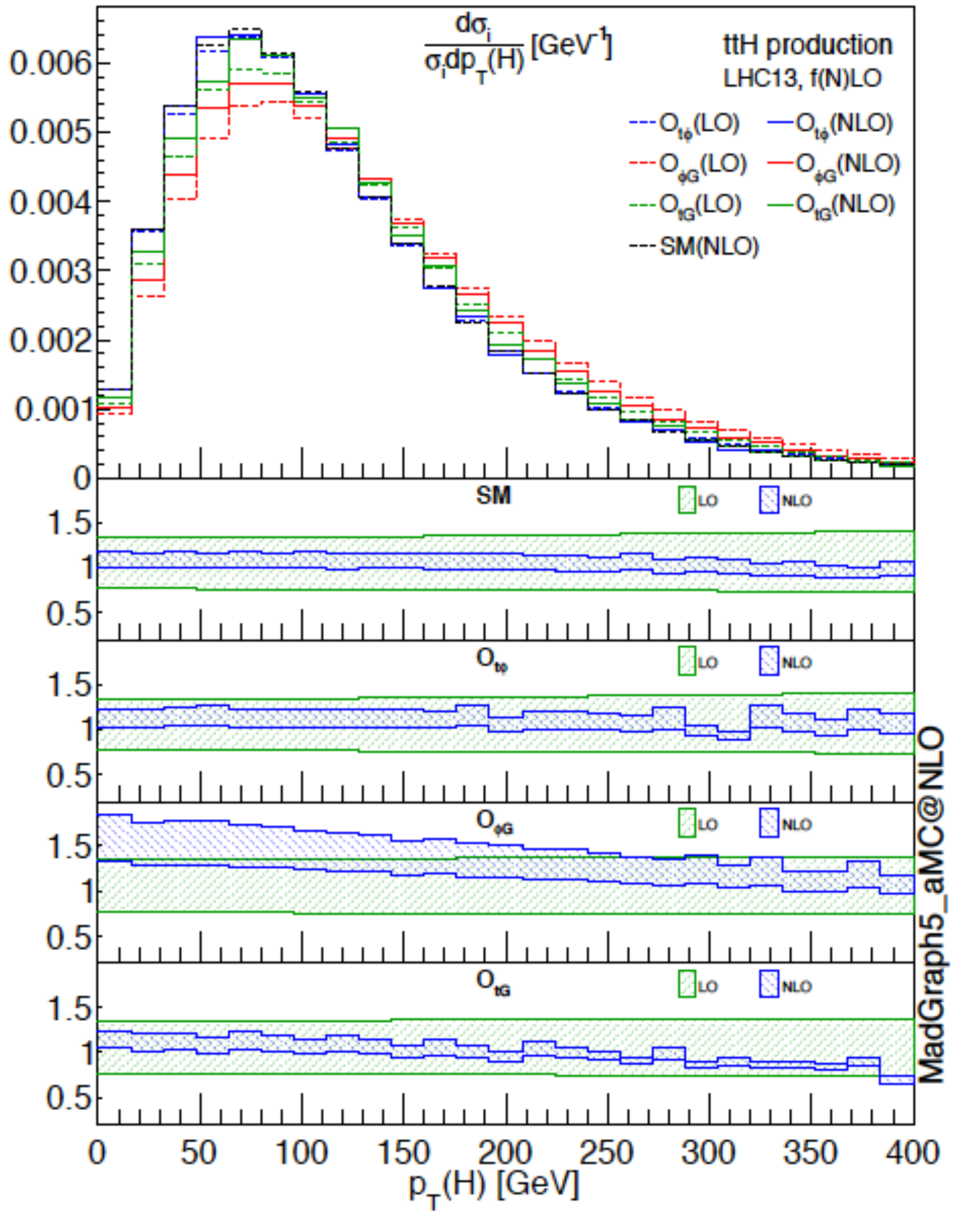


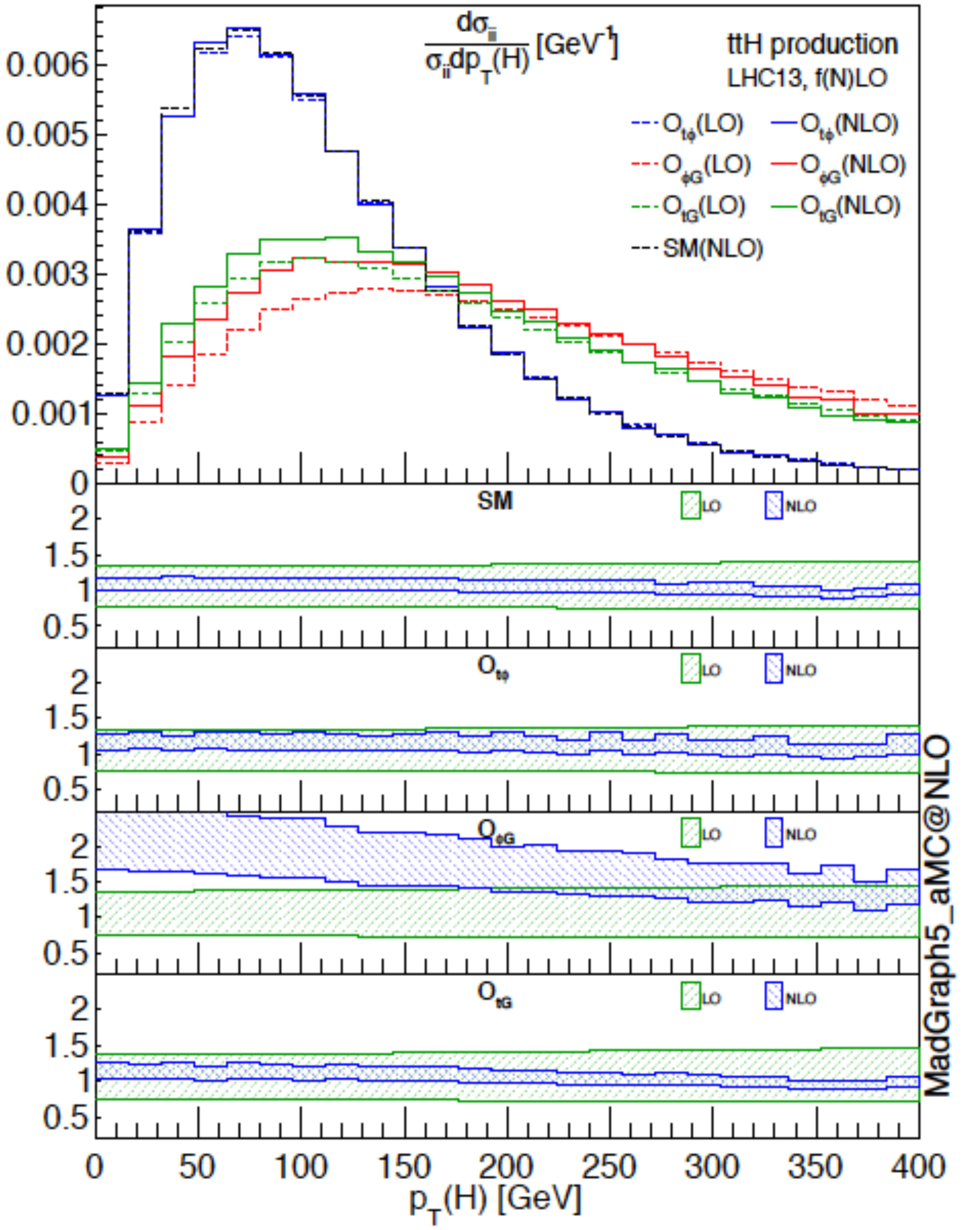
RG corrections not a good approximation to the NLO result, underestimate the NLO corrections

Milder EFT scale dependence at NLO, when mixing effects also taken into account

Comparison of exact NLO with LO improved by 1-loop RG running

Differential distributions for ttH





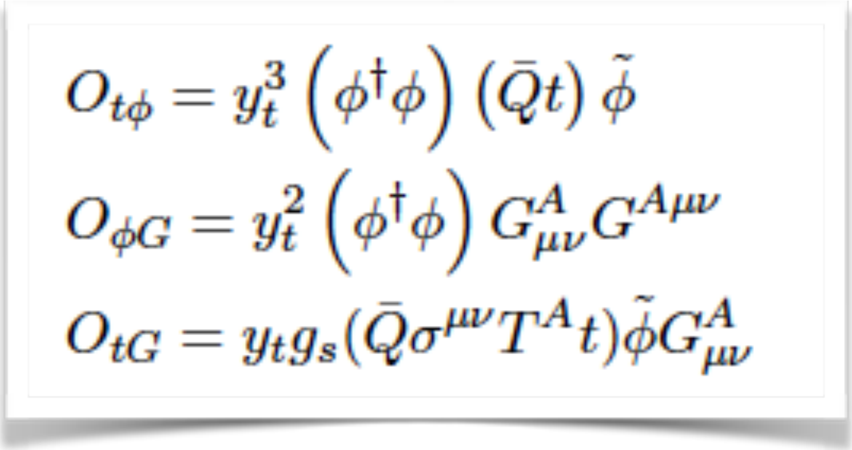
NLO: smaller uncertainties,
non-flat K-factors

Different shapes for different
operators for the squared terms

Maltoni, EV, Zhang arXiv:1607.05330

E.Vryonidou

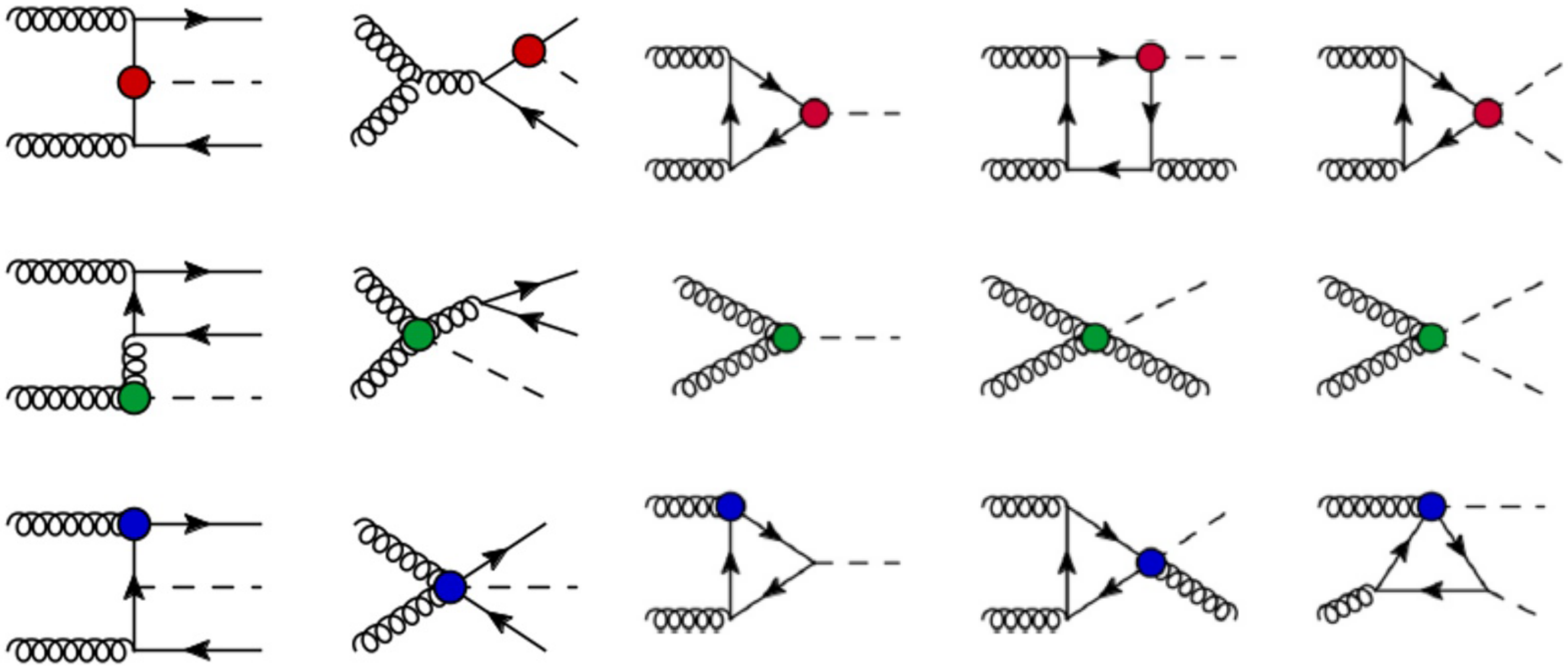
Top and Higgs



$$O_{t\phi} = y_t^3 \left(\phi^\dagger\phi\right) \left(\bar{Q}t\right) \tilde{\phi}$$

$$O_{\phi G} = y_t^2 \left(\phi^\dagger\phi\right) G^A_{\mu\nu} G^{A\mu\nu}$$

$$O_{tG} = y_t g_s (\bar{Q}\sigma^{\mu\nu} T^A t)\tilde{\phi} G^A_{\mu\nu}$$



ttH

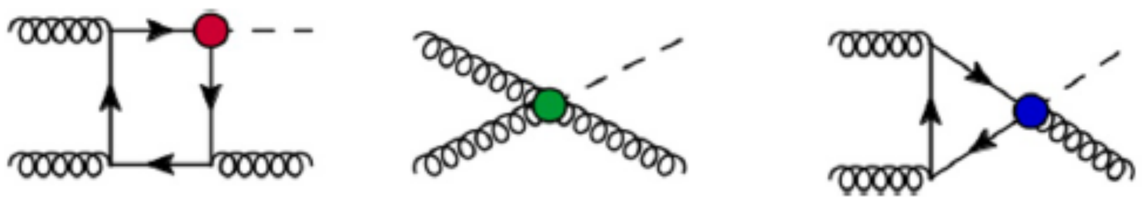
H, H+j, HH

See also
Degrande et al. arXiv:1205.1065
Grojean et al. arXiv:1312.3317
Azatov et al arXiv:1608.00977

Use with 1) ttH and 2) H, H+j to break degeneracy between operators and extract maximal information on these operators

Maltoni, EV, Zhang: arXiv:1607.05330

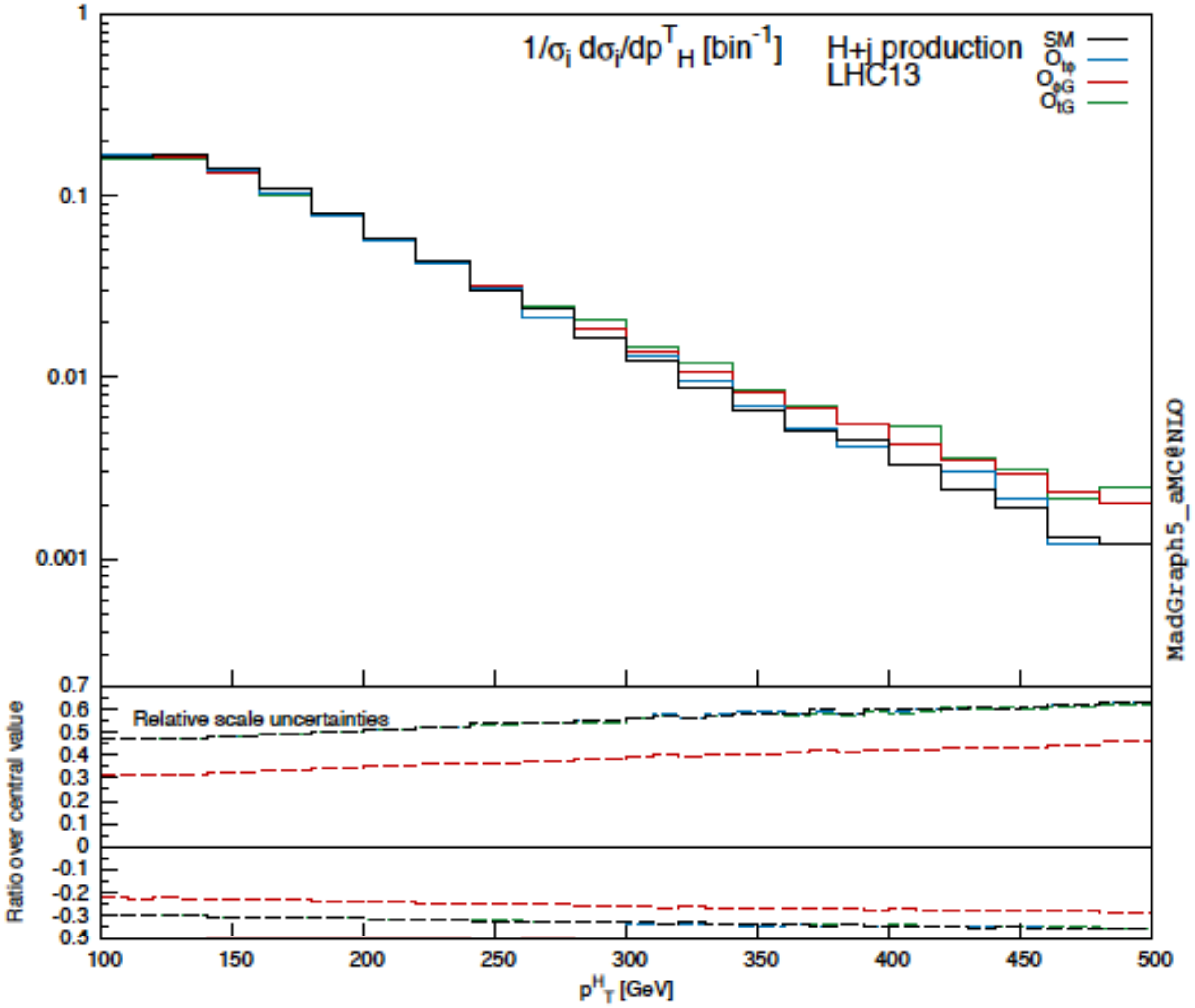
SMEFT in H+j

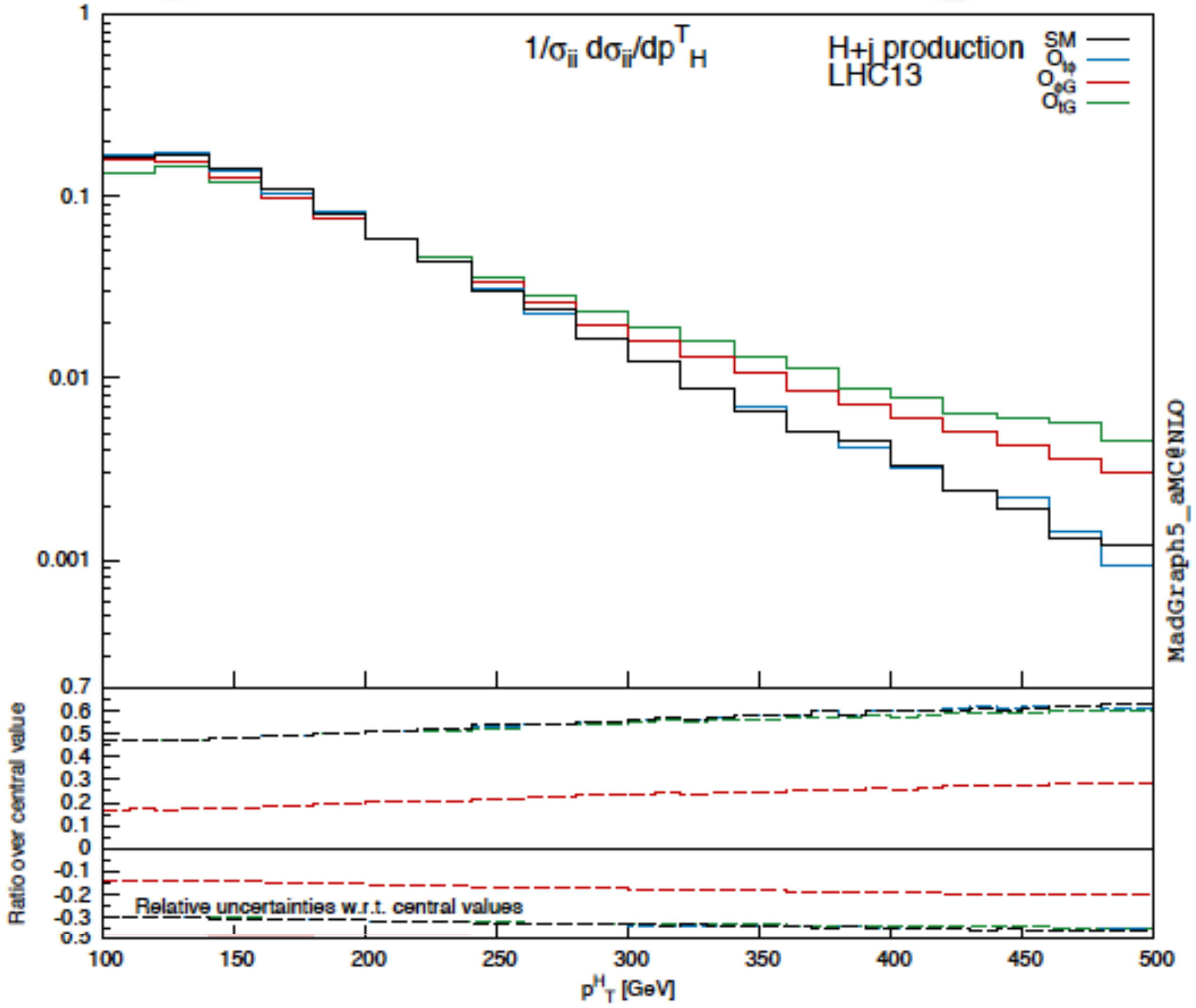


$$O_{t\phi} = y_t^3 \left(\phi^\dagger\phi\right)\left(\bar{Q}t\right)\tilde{\phi}$$

$$O_{\phi G} = y_t^2 \left(\phi^\dagger\phi\right) G^A_{\mu\nu}G^{A\mu\nu}$$

$$O_{tG} = y_t g_s(\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{\phi}G^A_{\mu\nu}$$

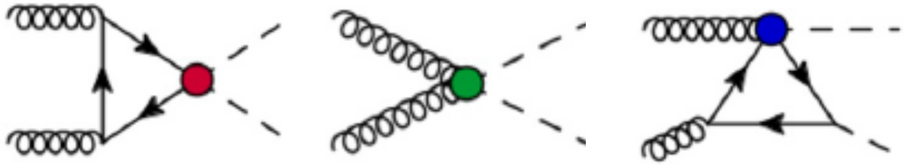




Harder tails from dim-6 operators: Boosted analysis

Maltoni, EV, Zhang: arXiv:1607.05330

SMEFT in HH

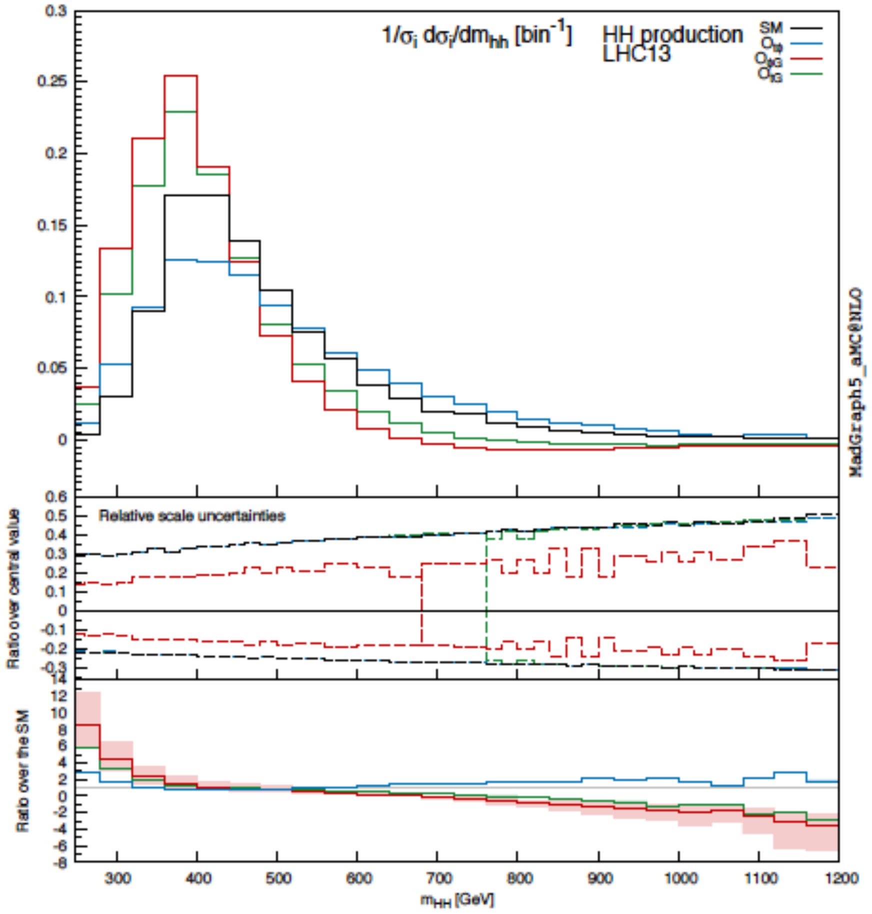


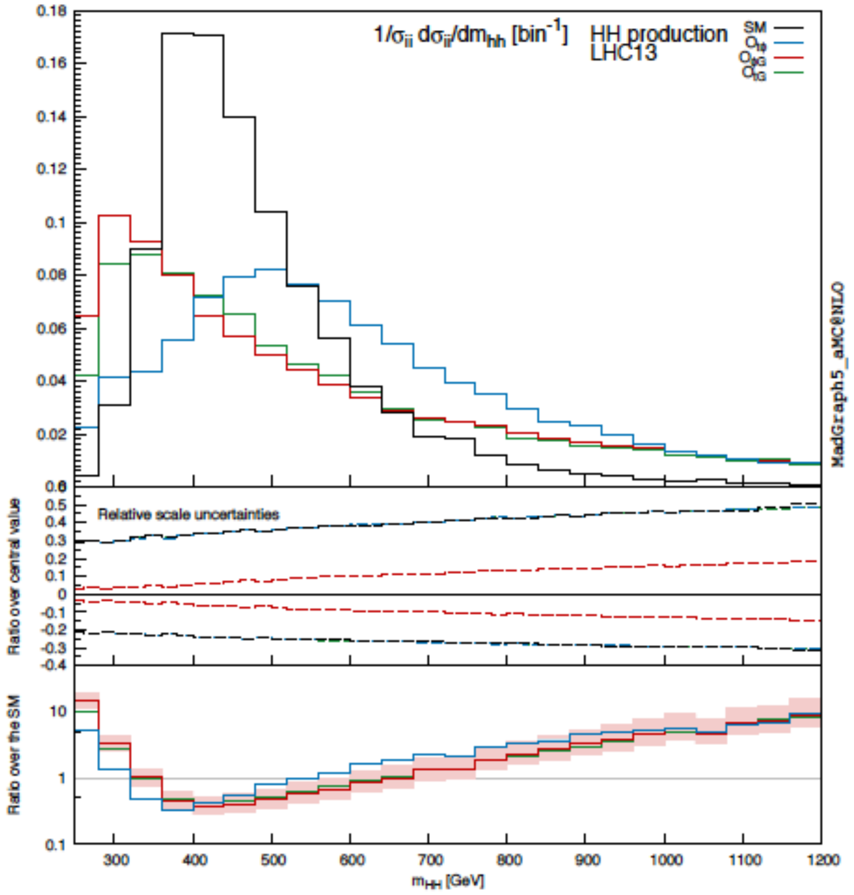
$$O_{t\phi} = y_t^3 \left(\phi^\dagger \phi\right) \left(\bar{Q} t\right) \tilde{\phi}$$

$$O_{\phi G} = y_t^2 \left(\phi^\dagger \phi\right) G^A_{\mu\nu} G^{A\mu\nu}$$

$$O_{tG} = y_t g_s (\bar{Q} \sigma^{\mu\nu} T^A t) \tilde{\phi} G^A_{\mu\nu}$$

Chromomagnetic operator computed for the first time

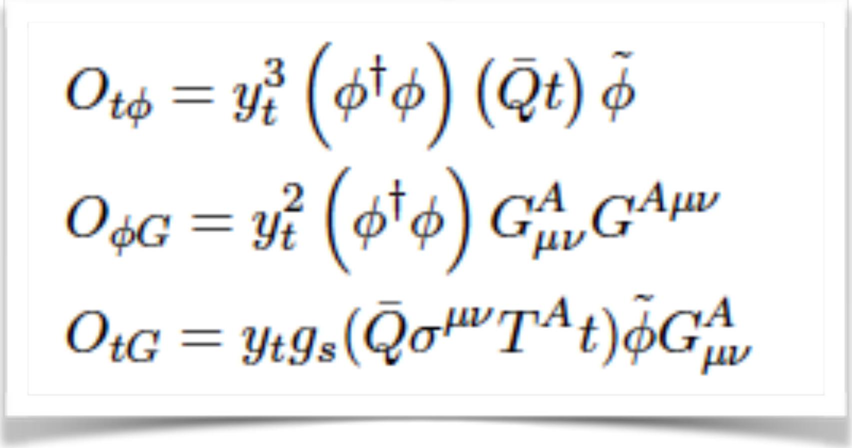




13 TeV	σ/σ_{SM} LO
σ_{SM}	$1.000^{+0.000+0.000}_{-0.000-0.000}$
$\sigma_{t\phi}$	$0.227^{+0.00114+0.0116}_{-0.000918-0.0101}$
$\sigma_{\phi G}$	$-47.3^{+6.18+3.707}_{-6.14-4.42}$
σ_{tG}	$-1.356^{+0.0271+0.161}_{-0.0225-0.051}$
$\sigma_{t\phi,t\phi}$	$0.0293^{+0.000727+0.0031}_{-0.000584-0.0026}$
$\sigma_{\phi G,\phi G}$	$2856.2^{+743.3+552}_{-628.5-425}$
$\sigma_{tG,tG}$	$1.940^{+0.0650+0.198}_{-0.0477-0.493}$
$\sigma_{t\phi,\phi G}$	$-11.83^{+1.39+1.42}_{-1.41-1.77}$
$\sigma_{t\phi,tG}$	$-0.340^{+0.000238+0.064}_{-0.000438-0.047}$
$\sigma_{\phi G,tG}$	$147.5^{+20.83+20.7}_{-18.86-31.4}$

To be investigated: the impact of the chromomagnetic operator in EFT analyses that focus on the extraction of the triple Higgs coupling λ (e.g. arXiv:1502.00539 and arXiv:1410.3471)

Constraints on the Wilson coefficients

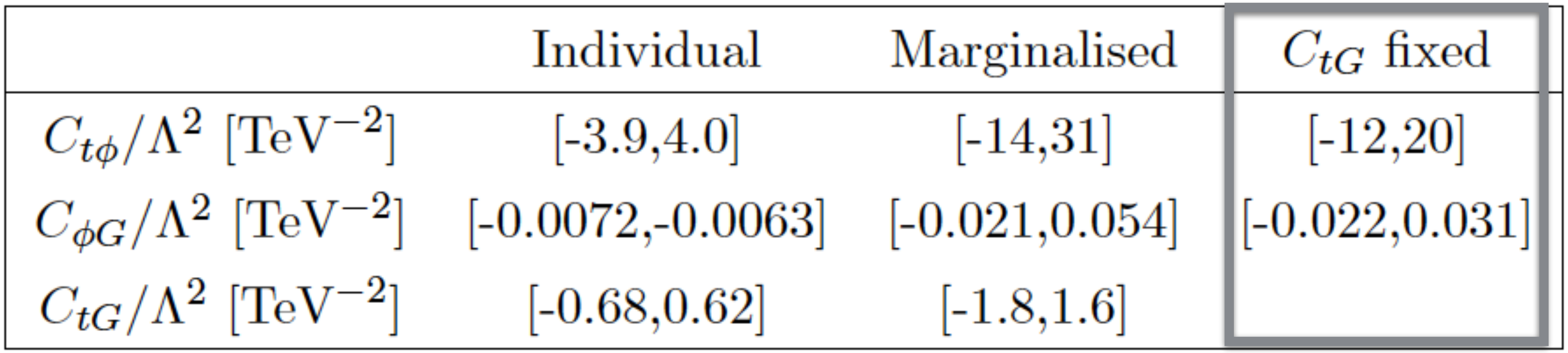


$$O_{t\phi} = y_t^3 \left(\phi^\dagger \phi\right) \left(\bar{Q}t\right) \tilde{\phi}$$

$$O_{\phi G} = y_t^2 \left(\phi^\dagger \phi\right) G^A_{\mu\nu} G^{A\mu\nu}$$

$$O_{tG} = y_t g_s (\bar{Q} \sigma^{\mu\nu} T^A t) \tilde{\phi} G^A_{\mu\nu}$$

Toy χ^2 fit for illustrative purposes using: single H, ttH Run I and Run II results
Impact of the 3 operators also included in Higgs decays



	Individual	Marginalised	C_{tG} fixed
$C_{t\phi}/\Lambda^2$ [TeV^{-2}]	[-3.9,4.0]	[-14,31]	[-12,20]
$C_{\phi G}/\Lambda^2$ [TeV^{-2}]	[-0.0072,-0.0063]	[-0.021,0.054]	[-0.022,0.031]
C_{tG}/Λ^2 [TeV^{-2}]	[-0.68,0.62]	[-1.8,1.6]	

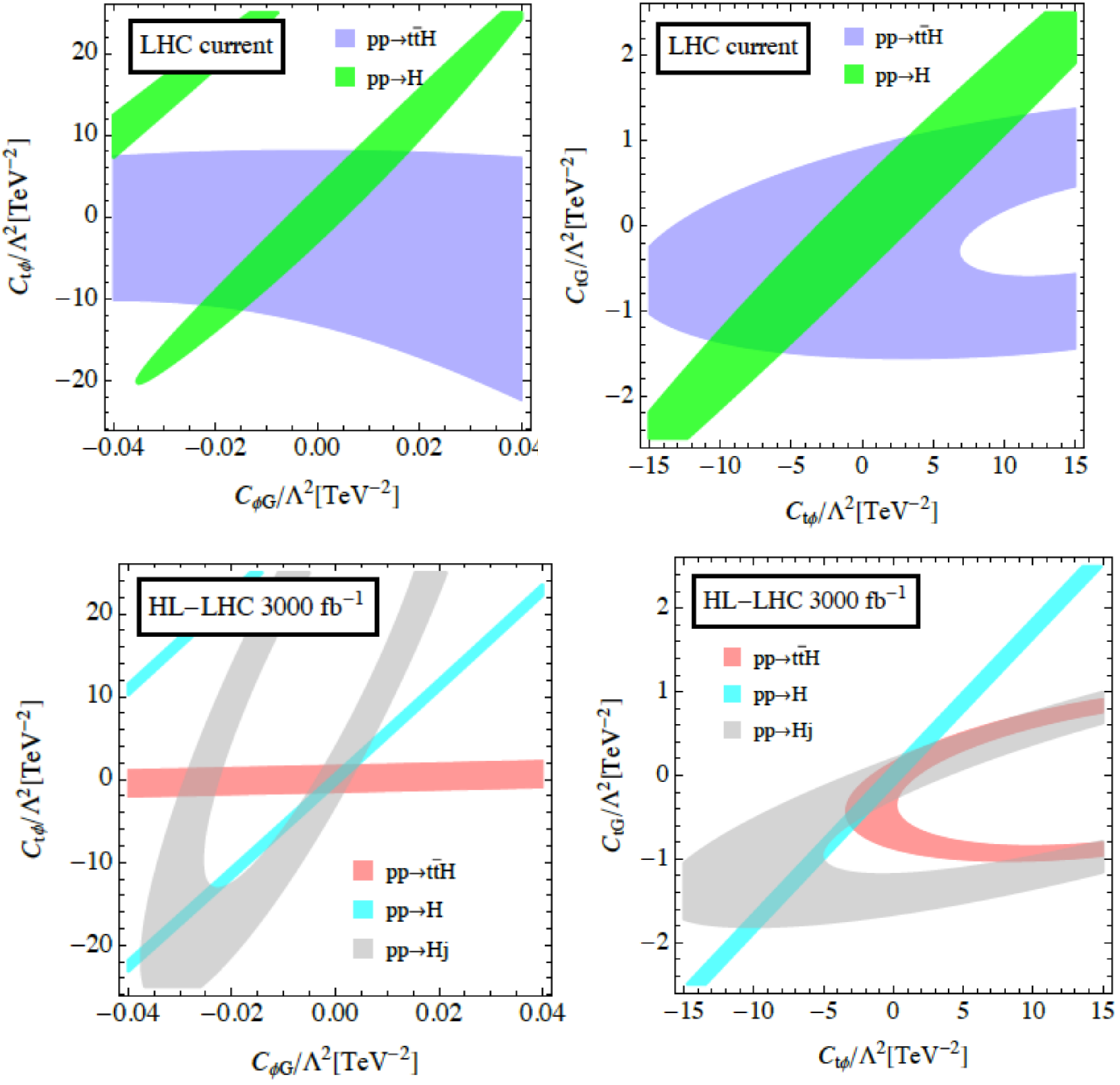
95% c.l.

typically C_{tG}=0 in Higgs analyses

- Individual limit on C_{tG} comparable to the one from top pair production-room to improve with ttH measurement in run II
- Including the chromomagnetic operator leaves much more space to the other two operators

Need for global analysis

Constraints using two-operator fits



Current limits using LHC measurements

$$O_{t\phi} = y_t^3 \left(\phi^\dagger \phi\right) \left(\bar{Q} t\right) \tilde{\phi}$$

$$O_{\phi G} = y_t^2 \left(\phi^\dagger \phi\right) G^A_{\mu\nu} G^{A\mu\nu}$$

$$O_{tG} = y_t g_s (\bar{Q} \sigma^{\mu\nu} T^A t) \tilde{\phi} G^A_{\mu\nu}$$

14TeV projection 3000 fb^{-1}

Maltoni, EV, Zhang
arXiv:1607.05330

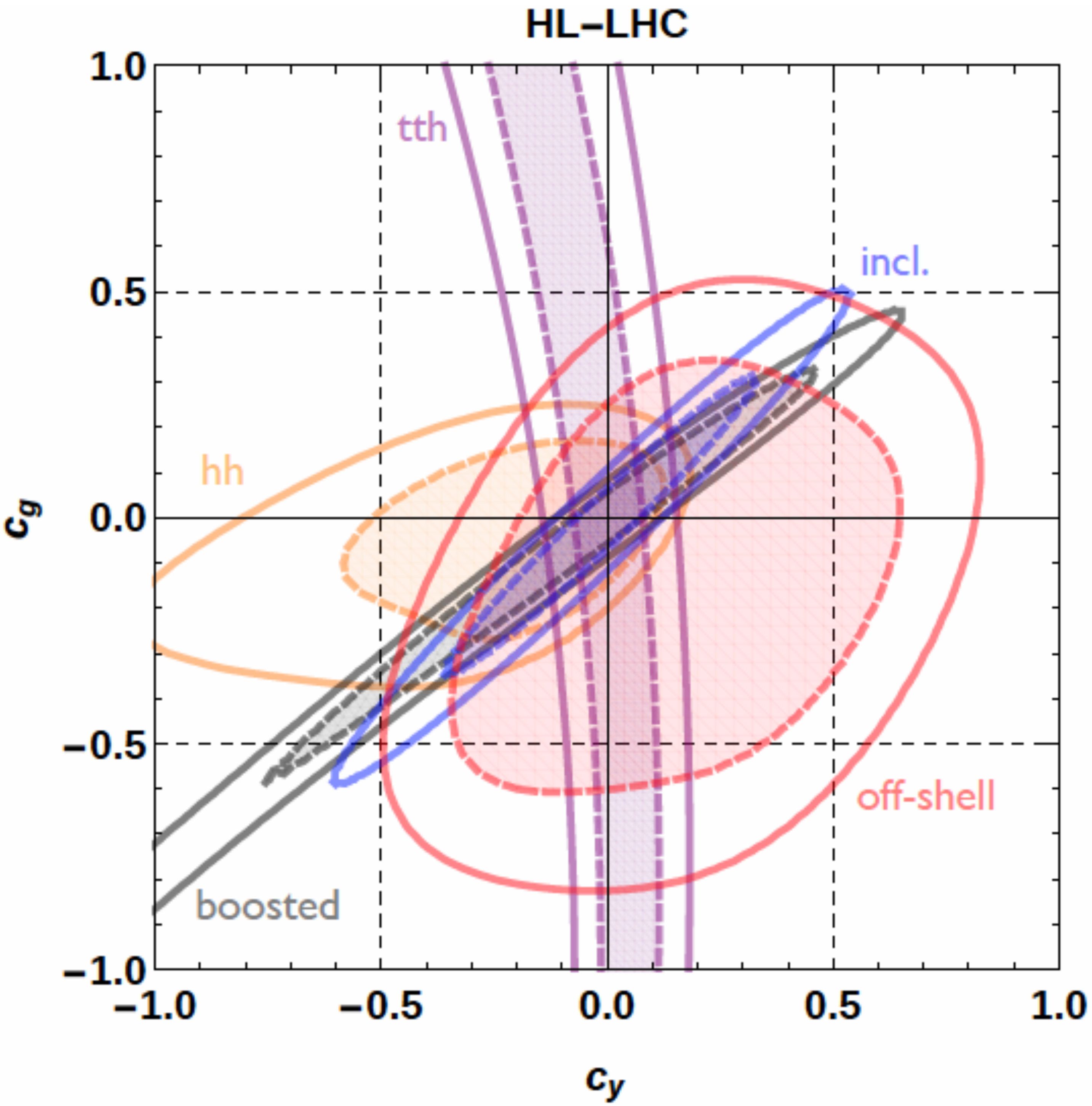
How to extract maximal information?

$$O_{t\phi} = y_t^3 \left(\phi^\dagger\phi\right) (\bar{Q}t)\, \tilde{\phi}$$

$$O_{\phi G} = y_t^2 \left(\phi^\dagger\phi\right) G^A_{\mu\nu} G^{A\mu\nu}$$

Combination:

- inclusive H
- boosted Higgs
- ttH
- HH
- off-shell Higgs



Azatov et al arXiv:1608.00977

Outlook

- SMEFT a consistent way to look for new interactions
- Higher-order corrections needed to match SM precision and experimental accuracy
- Progress in top-quark processes: pair production, single top, tt+V, tt+H as well as loop-induced processes
- QCD corrections important both for total cross-sections and distributions: SM k-factors are not enough
- Global fits results already available: important to include NLO predictions where available to extract maximal and more reliable information
- Combination of Higgs and top results is crucial for a global EFT fit

Thank you for your attention