Effective Field Theory at the LHC

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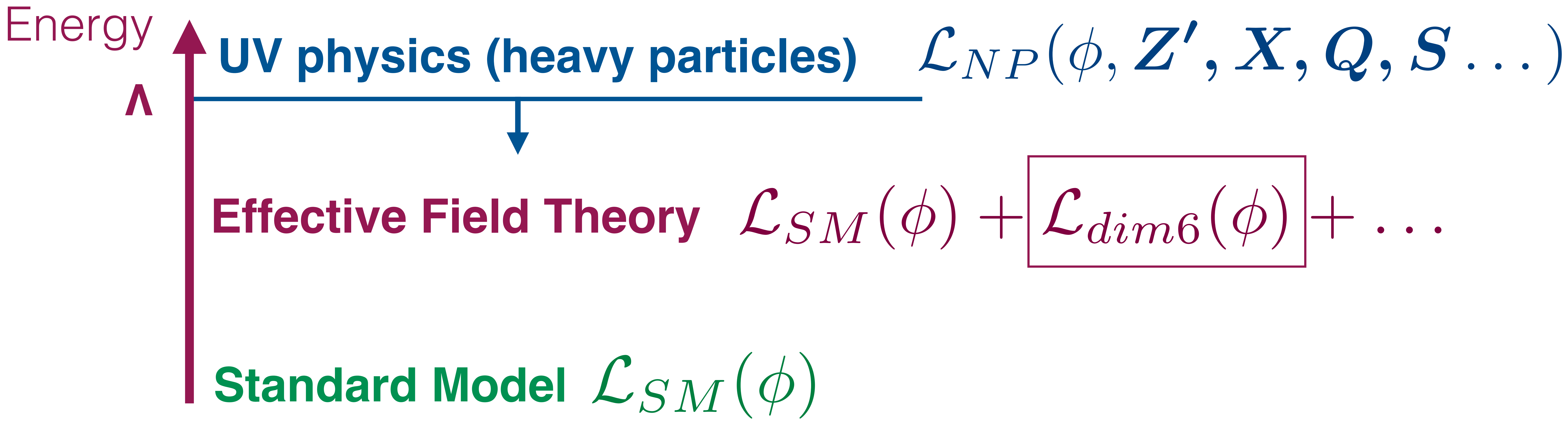
THE ROYAL SOCIETY

DIS2021, Altarelli Prize Award Ceremony
16/4/21

EFT

A model independent probe of heavy New Physics



Effective Field Theory reveals high energy physics through precise measurements at low energy: **A new era in particle physics**

SMEFT basics

A theoretically consistent framework

→ New Interactions of SM particles

Buchmuller, Wyler Nucl.Phys. B268 (1986) 621-653

Grzadkowski et al JHEP 1010 (2010) 085

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_i \frac{C_i^{(6)} O_i^{(6)}}{\Lambda^2} + \mathcal{O}(\Lambda^{-4})$$

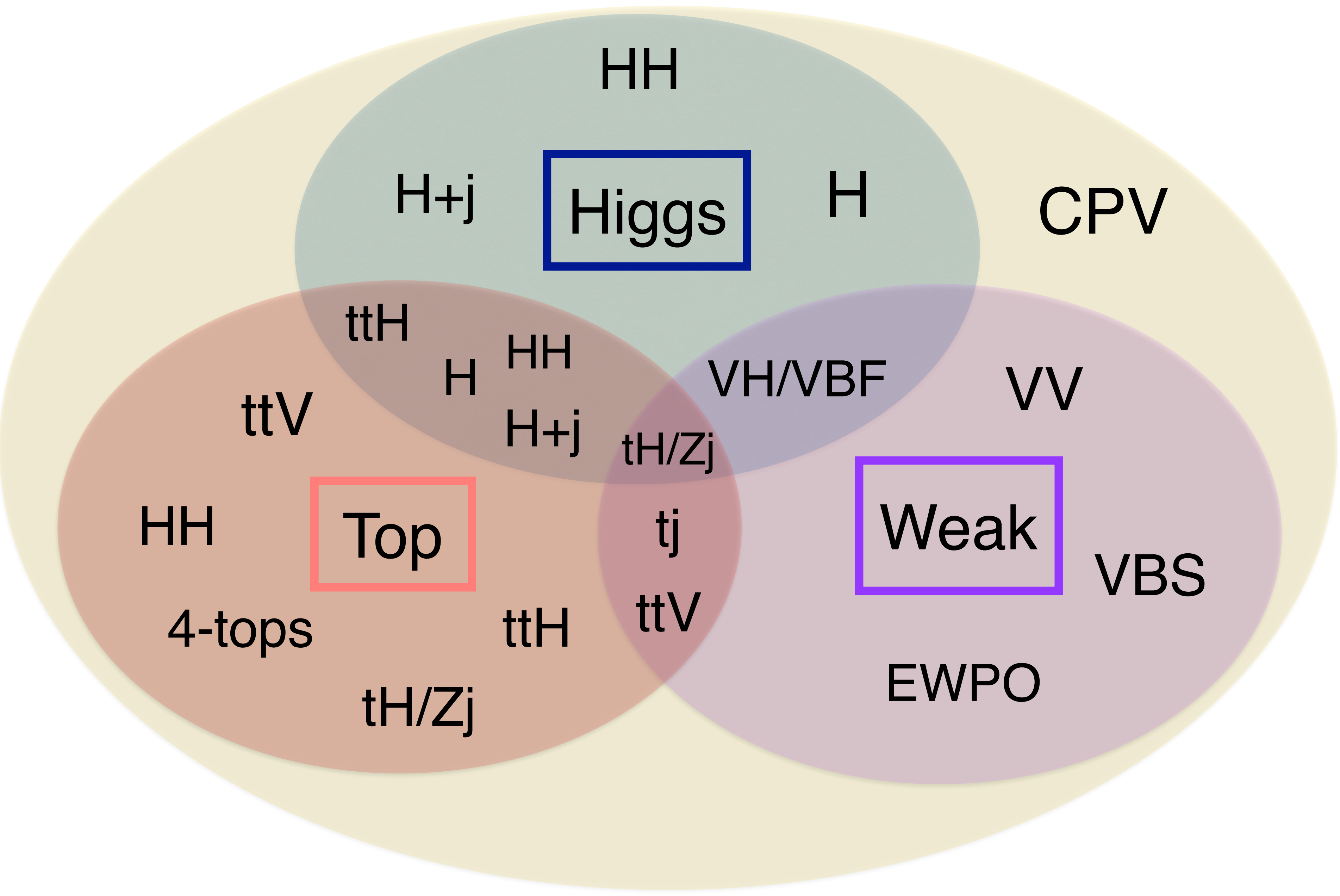
X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar l_p e_r \varphi)$
$Q_{\widetilde G}$	$f^{ABC} \widetilde G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p u_r \widetilde\varphi)$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star \left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p d_r \varphi)$
$Q_{\widetilde W}$	$\varepsilon^{IJK} \widetilde W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar l_p \sigma^{\mu\nu} e_r)\tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar l_p \gamma^\mu l_r)$
$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\, \widetilde G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar l_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I \varphi)(\bar l_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uG}	$(\bar q_p \sigma^{\mu\nu} T^A u_r)\widetilde\varphi\, G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar e_p \gamma^\mu e_r)$
$Q_{\varphi\widetilde W}$	$\varphi^\dagger\varphi\, \widetilde W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uW}	$(\bar q_p \sigma^{\mu\nu} u_r)\tau^I \widetilde\varphi\, W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar q_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar q_p \sigma^{\mu\nu} u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I \varphi)(\bar q_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\, \widetilde B_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar q_p \sigma^{\mu\nu} T^A d_r)\varphi\, G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar u_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W_{\mu\nu}^I B^{\mu\nu}$	Q_{dW}	$(\bar q_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar d_p \gamma^\mu d_r)$
$Q_{\varphi\widetilde WB}$	$\varphi^\dagger\tau^I\varphi\, \widetilde W_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar q_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu\varphi)(\bar u_p \gamma^\mu d_r)$

$(\bar LL)(\bar LL)$		$(\bar RR)(\bar RR)$		$(\bar LL)(\bar RR)$	
Q_{ll}	$(\bar l_p \gamma_\mu l_r)(\bar l_s \gamma^\mu l_t)$	Q_{ee}	$(\bar e_p \gamma_\mu e_r)(\bar e_s \gamma^\mu e_t)$	Q_{le}	$(\bar l_p \gamma_\mu l_r)(\bar e_s \gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar q_s \gamma^\mu q_t)$	Q_{uu}	$(\bar u_p \gamma_\mu u_r)(\bar u_s \gamma^\mu u_t)$	Q_{lu}	$(\bar l_p \gamma_\mu l_r)(\bar u_s \gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar q_p \gamma_\mu \tau^I q_r)(\bar q_s \gamma^\mu \tau^I q_t)$	Q_{dd}	$(\bar d_p \gamma_\mu d_r)(\bar d_s \gamma^\mu d_t)$	Q_{ld}	$(\bar l_p \gamma_\mu l_r)(\bar d_s \gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar l_p \gamma_\mu l_r)(\bar q_s \gamma^\mu q_t)$	Q_{eu}	$(\bar e_p \gamma_\mu e_r)(\bar u_s \gamma^\mu u_t)$	Q_{qe}	$(\bar q_p \gamma_\mu q_r)(\bar e_s \gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar l_p \gamma_\mu \tau^I l_r)(\bar q_s \gamma^\mu \tau^I q_t)$	Q_{ed}	$(\bar e_p \gamma_\mu e_r)(\bar d_s \gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar u_s \gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar u_p \gamma_\mu u_r)(\bar d_s \gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar q_p \gamma_\mu T^A q_r)(\bar u_s \gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar u_p \gamma_\mu T^A u_r)(\bar d_s \gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar d_s \gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar q_p \gamma_\mu T^A q_r)(\bar d_s \gamma^\mu T^A d_t)$

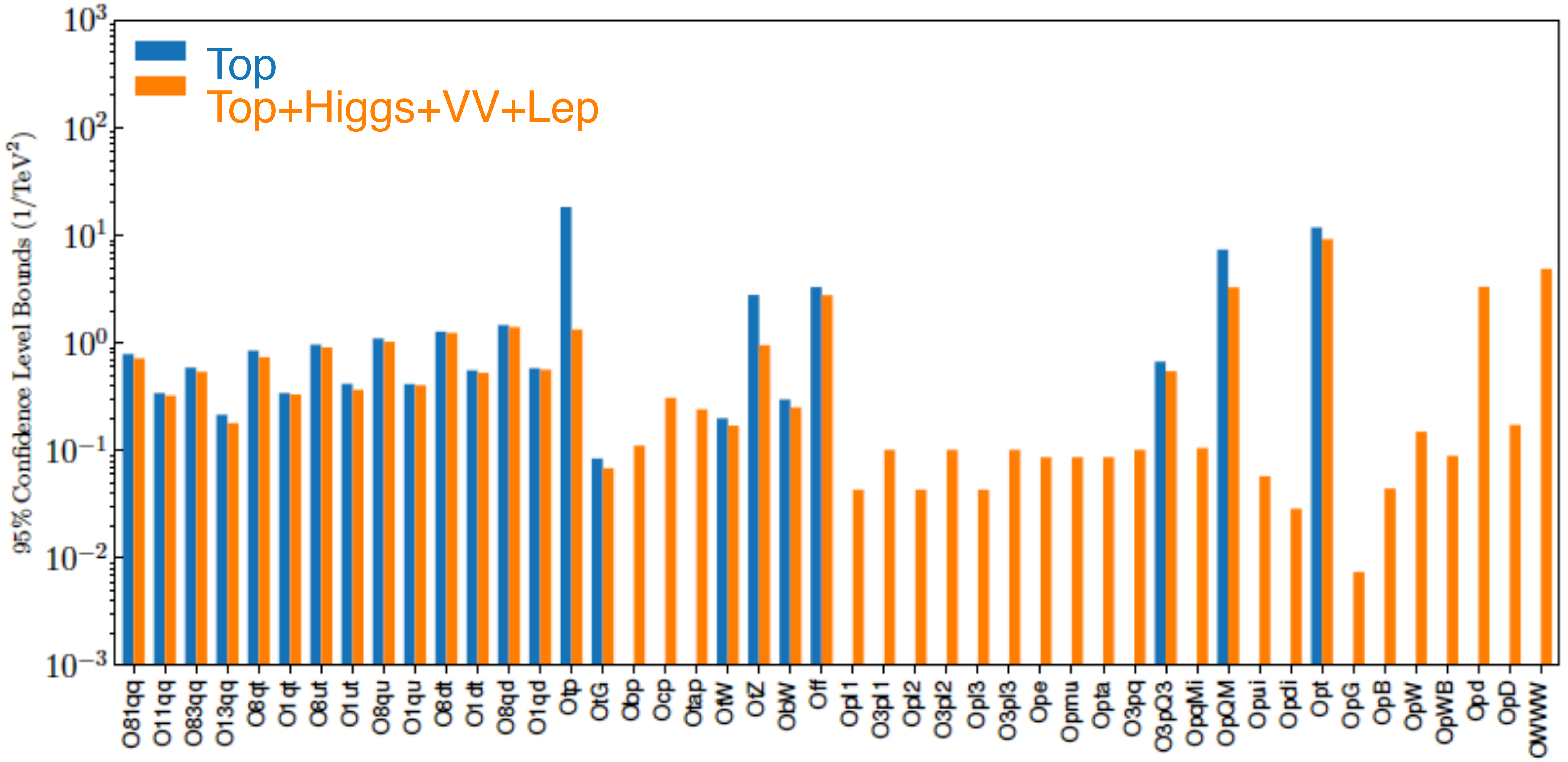
$(\bar LR)(\bar RL)$ and $(\bar LR)(\bar LR)$		B-violating	
Q_{ledq}	$(\bar l_p^j e_r)(\bar d_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q_{quqd}^{(1)}$	$(\bar q_p^j u_r)\varepsilon_{jk}(\bar q_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{quqd}^{(8)}$	$(\bar q_p^j T^A u_r)\varepsilon_{jk}(\bar q_s^k T^A d_t)$	$Q_{qqq}^{(1)}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar l_p^j e_r)\varepsilon_{jk}(\bar q_s^k u_t)$	$Q_{qqq}^{(3)}$	$\varepsilon^{\alpha\beta\gamma}(\tau^I\varepsilon)_{jk}(\tau^I\varepsilon)_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(3)}$	$(\bar l_p^j \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar q_s^k \sigma^{\mu\nu} u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$

SMEFT

The global aspect



Adapted from K. Mimasu



Ethier, Maltoni, Mantani, Nocera, Rojo, EV and Zhang in preparation

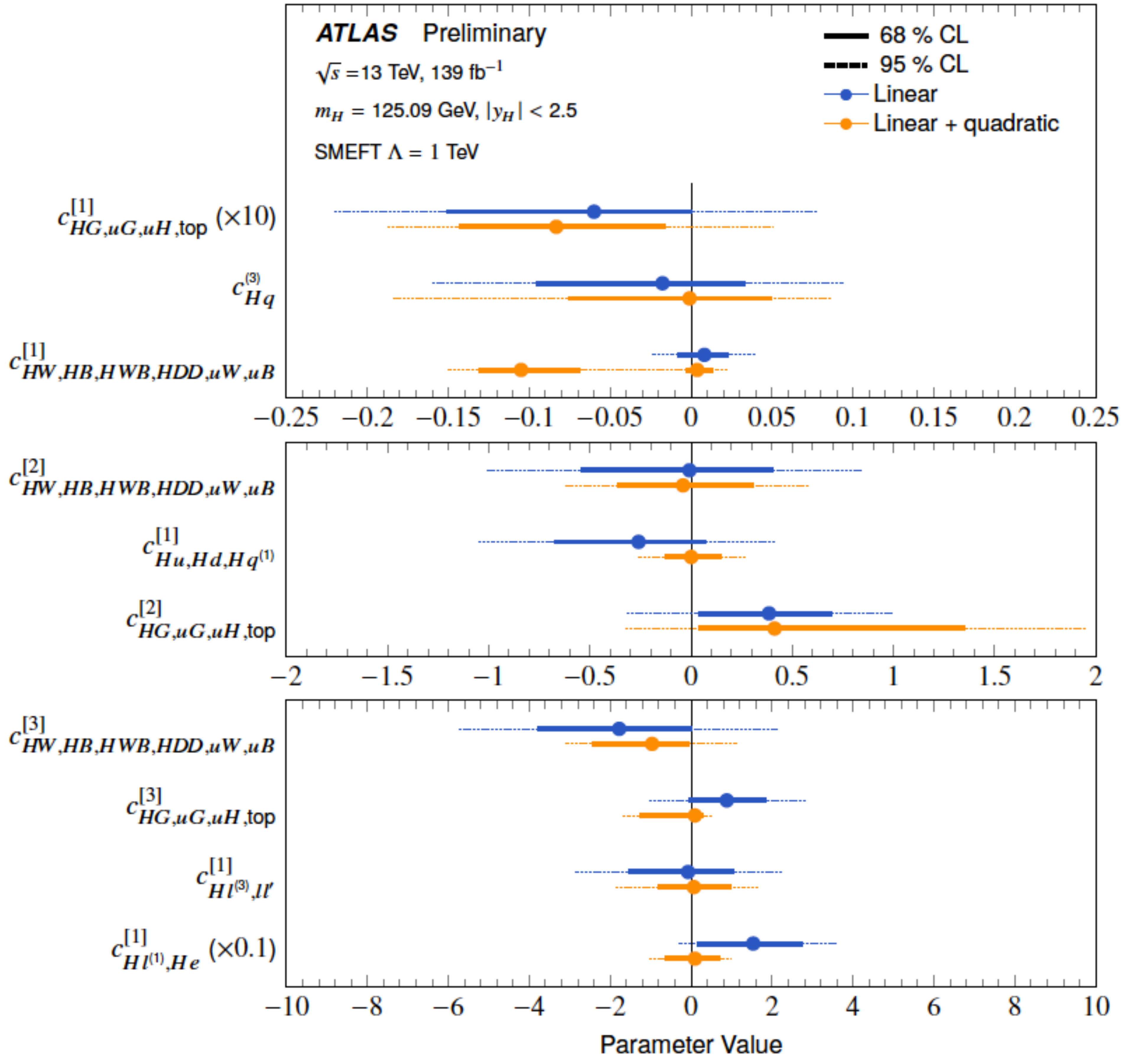
Global fit of the top+Higgs+EW sectors

SMEFT correlates different sectors: Global interpretations are needed

SMEFT

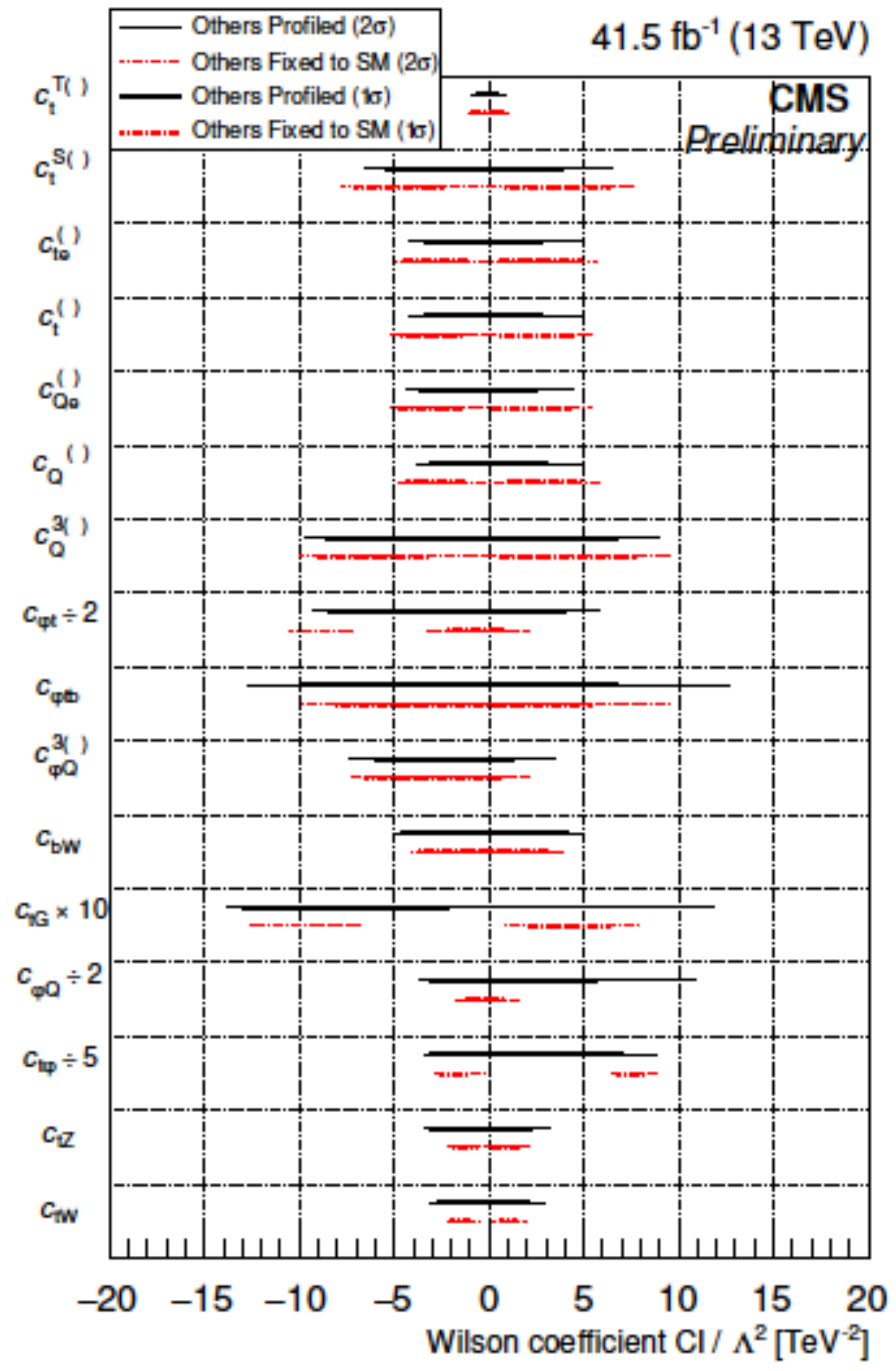
Not just a theorists' tool

ATLAS CONF-2020-053



CMS TOP-19-001

$t\bar{t}l\nu, t\bar{t}l\bar{l}, tl\bar{l}q, tHq$



What's the path to New Physics?

How to maximise the reach of EFT?

Use SMEFT to look for deviations from SM predictions

=

Use as many experimental measurements as possible
Cross-sections+differential distributions

+

Use the best SM predictions
QCD/EW corrections

+

Use precise SMEFT predictions to maximise sensitivity

Aspects of EFT predictions

And how to improve them

- Higher Orders in $1/\Lambda^4$
  - squared dim-6 contributions
  - double insertions of dim-6
  - dim-8 contributions
- Higher Orders in QCD and EW
  - EFT is a QFT, renormalisable order-by-order $1/\Lambda^2$

$$\mathcal{O}(\alpha_s, \alpha_{ew}) + \mathcal{O}\left(\frac{1}{\Lambda^2}\right) + \mathcal{O}\left(\frac{\alpha_s}{\Lambda^2}\right) + \mathcal{O}\left(\frac{\alpha_{ew}}{\Lambda^2}\right)$$

Most of my work focuses on this

Long History

~50 years ago

Volume 52B, number 3 PHYSICS LETTERS 14 October 1974

OCTET ENHANCEMENT OF NON-LEPTONIC WEAK INTERACTIONS IN ASYMPTOTICALLY FREE GAUGE THEORIES

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Received 22 June 1974

Octet enhancement of weak non leptonic amplitudes is found to occur in asymptotically free gauge theories of strong interactions, combined with unified weak and e.m. interactions. The order of magnitude of the enhancement factor for different models is discussed.

Four fermion operators (dimension six). For these operators we can restrict to the massless fermion theory, so that the coefficients C_k will obey chiral $SU(n) \otimes SU(n)$ selection rules. This restricts the operators to be considered to:

$$O_L^1 = \bar{\psi}\gamma_\mu L^+(1+\gamma_5)\psi\bar{\psi}\gamma^\mu L^-(1+\gamma_5)\psi$$
$$O_L^2 = \bar{\psi}\gamma_\mu L^+(1+\gamma_5)t^A\psi\bar{\psi}\gamma^\mu L^-(1+\gamma_5)t^A\psi \quad (4)$$

$$O_R^1 = \bar{\psi}\gamma_\mu R^+(1-\gamma_5)\psi\bar{\psi}\gamma^\mu R^-(1-\gamma_5)\psi$$
$$O_R^2 = \bar{\psi}\gamma_\mu R^+(1-\gamma_5)t^A\psi\bar{\psi}\gamma^\mu R^-(1-\gamma_5)t^A\psi \quad (5)$$

$$O_{LR}^1 = \bar{\psi}\gamma_\mu L^+(1+\gamma_5)\psi\bar{\psi}\gamma^\mu R^-(1-\gamma_5)\psi + \text{h.c.}$$
$$O_{LR}^2 = \bar{\psi}\gamma_\mu L^+(1+\gamma_5)t^A\psi\bar{\psi}\gamma^\mu R^-(1-\gamma_5)t^A\psi + \text{h.c.} \quad (6)$$

QCD corrections and renormalisation of dimension-6 operators, pioneering work by Guido!

~1000 citations

'**These important papers were the first calculations of the QCD corrections to the coefficients of the Wilson expansion in the product of two weak currents,** an approach that, suitably generalised (by considering other weak processes) and improved (for example, by computing the anomalous dimensions beyond the leading order), still represents a basic tool in this field.'

G. Altarelli: The Early Days of QCD arXiv:1106.3189

Why bother with higher orders?

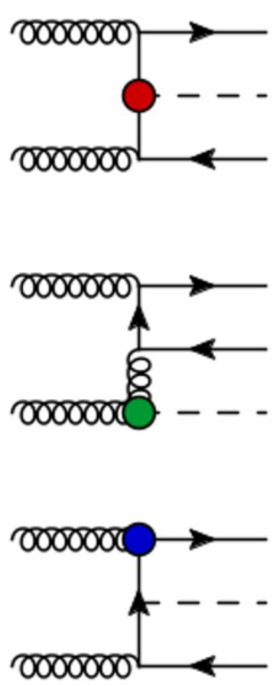
Higher orders in SMEFT bring:

* Accuracy
* Precision
* Improved sensitivity
  * Accurate knowledge of the deviations (distribution shapes, correlations between observables, etc.) can be the key to disentangle them from the SM.
  * Loop-induced new sensitivity: new operators entering at one-loop

Accuracy and precision

Rates and distributions

ttH



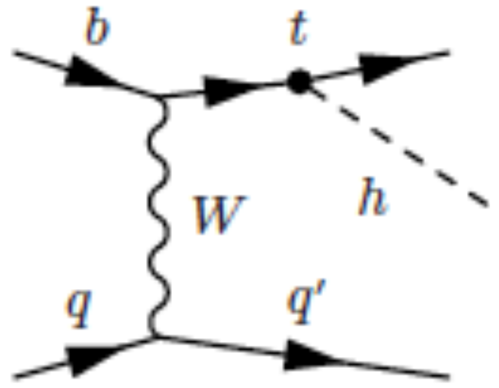
13 TeV	σ NLO	K
σ_{SM}	$0.507^{+0.030+0.000+0.007}_{-0.048-0.000-0.008}$	1.09
$\sigma_{t\phi}$	$-0.062^{+0.006+0.001+0.001}_{-0.004-0.001-0.001}$	1.13
$\sigma_{\phi G}$	$0.872^{+0.131+0.037+0.013}_{-0.123-0.035-0.016}$	1.39
σ_{tG}	$0.503^{+0.025+0.001+0.007}_{-0.046-0.003-0.008}$	1.07
$\sigma_{t\phi,t\phi}$	$0.0019^{+0.0001+0.0001+0.0000}_{-0.0002-0.0000-0.0000}$	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

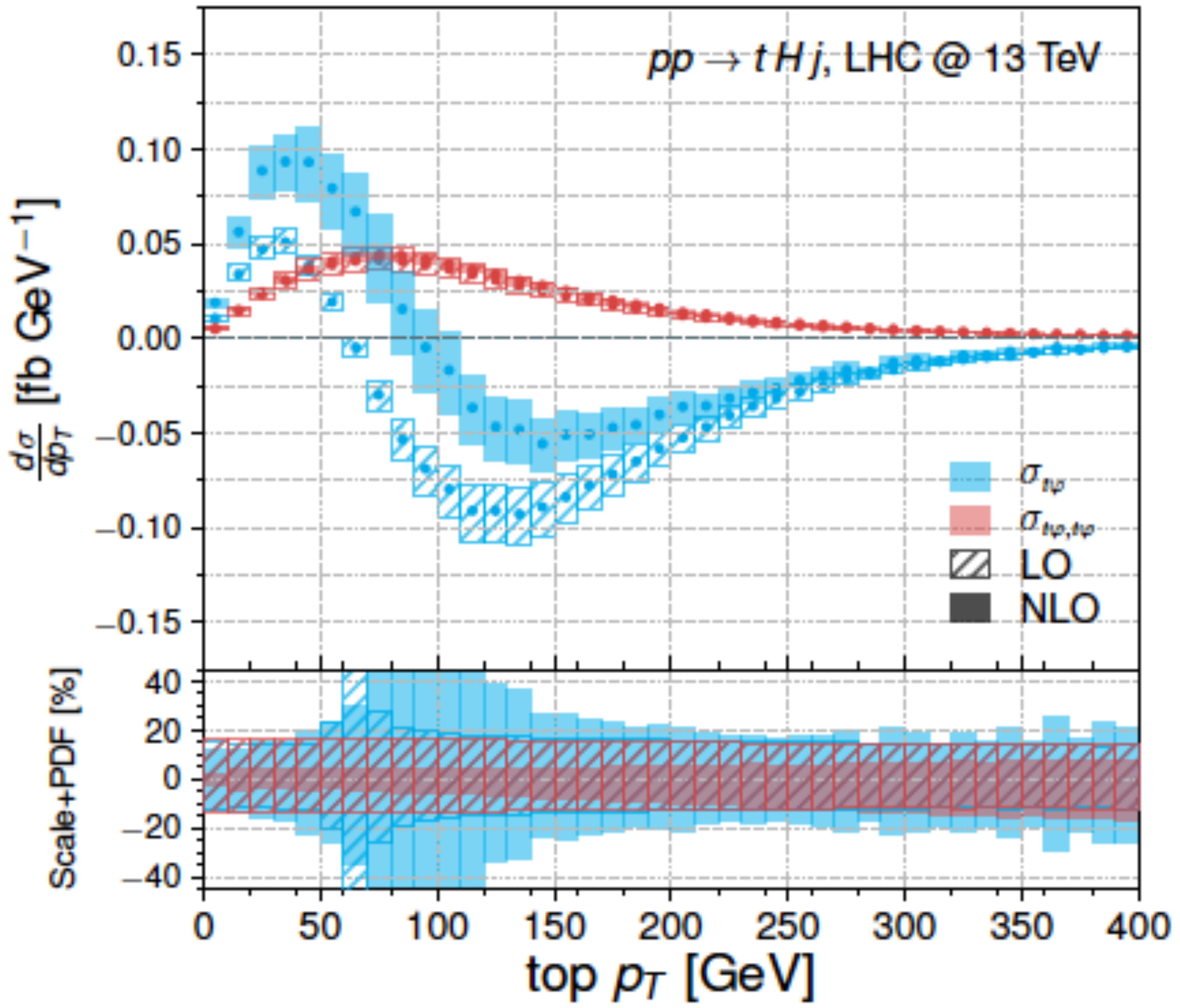
$$\sigma = \sigma_{\rm SM} + \sum_i \frac{1{\rm TeV}^2}{\Lambda^2} C_i \sigma_i + \sum_{i\leq j} \frac{1{\rm TeV}^4}{\Lambda^4} C_i C_j \sigma_{ij}.$$

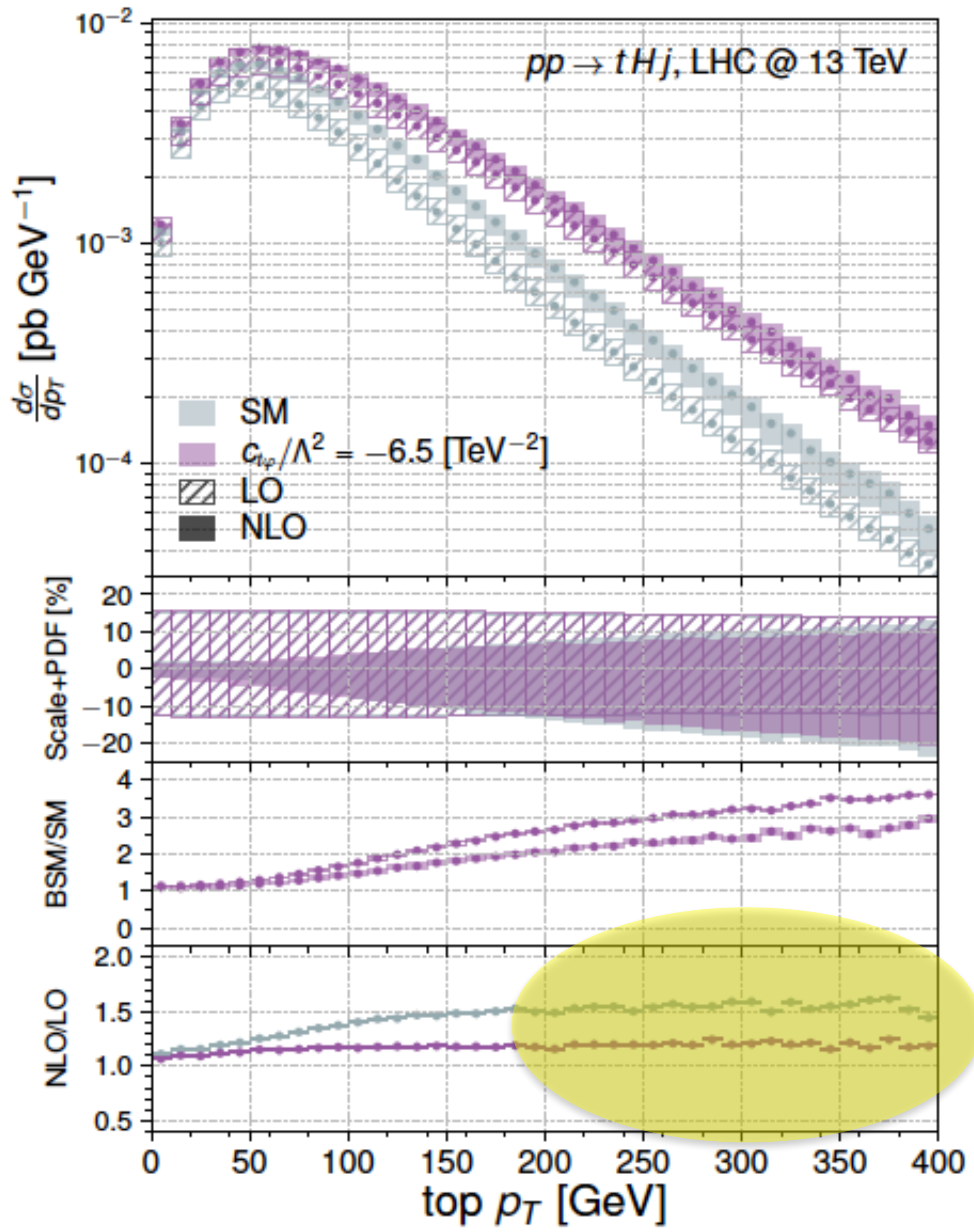
Different K-factors for different operators, different from the SM

Maltoni, EV, Zhang arXiv:1607.05330

tHj







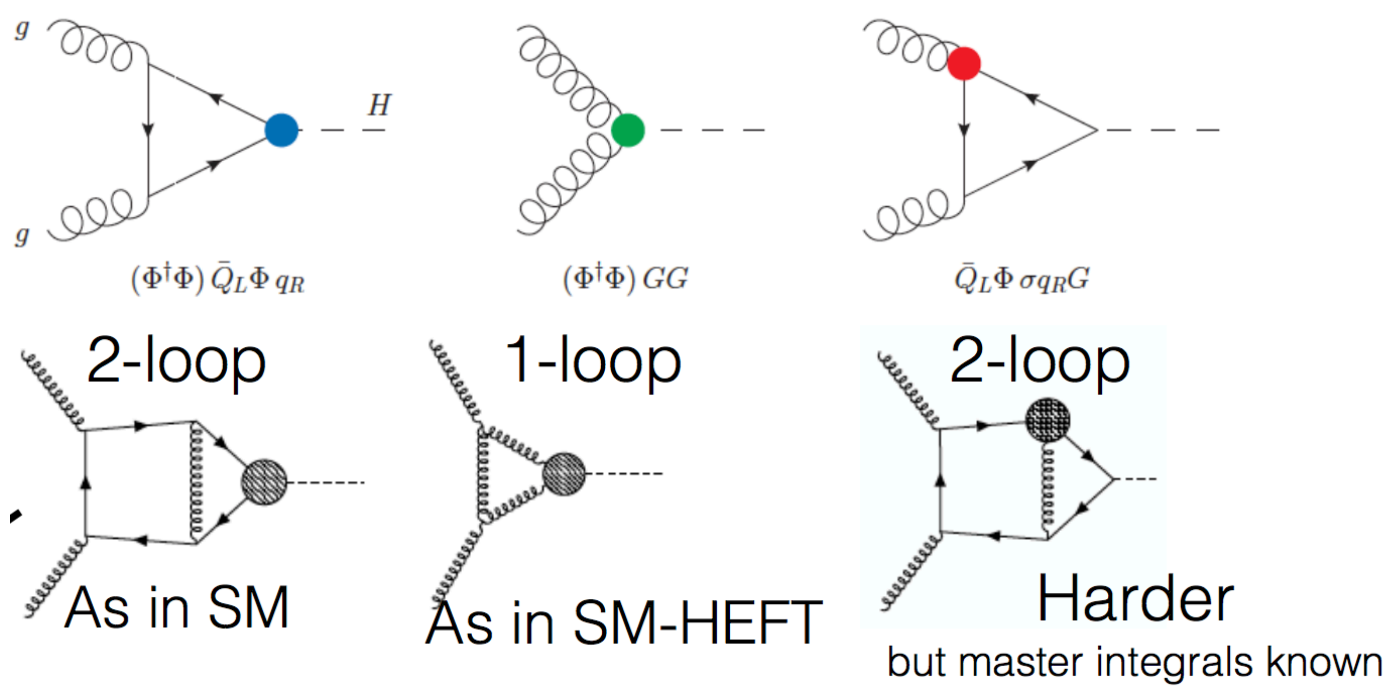
Different shapes at NLO

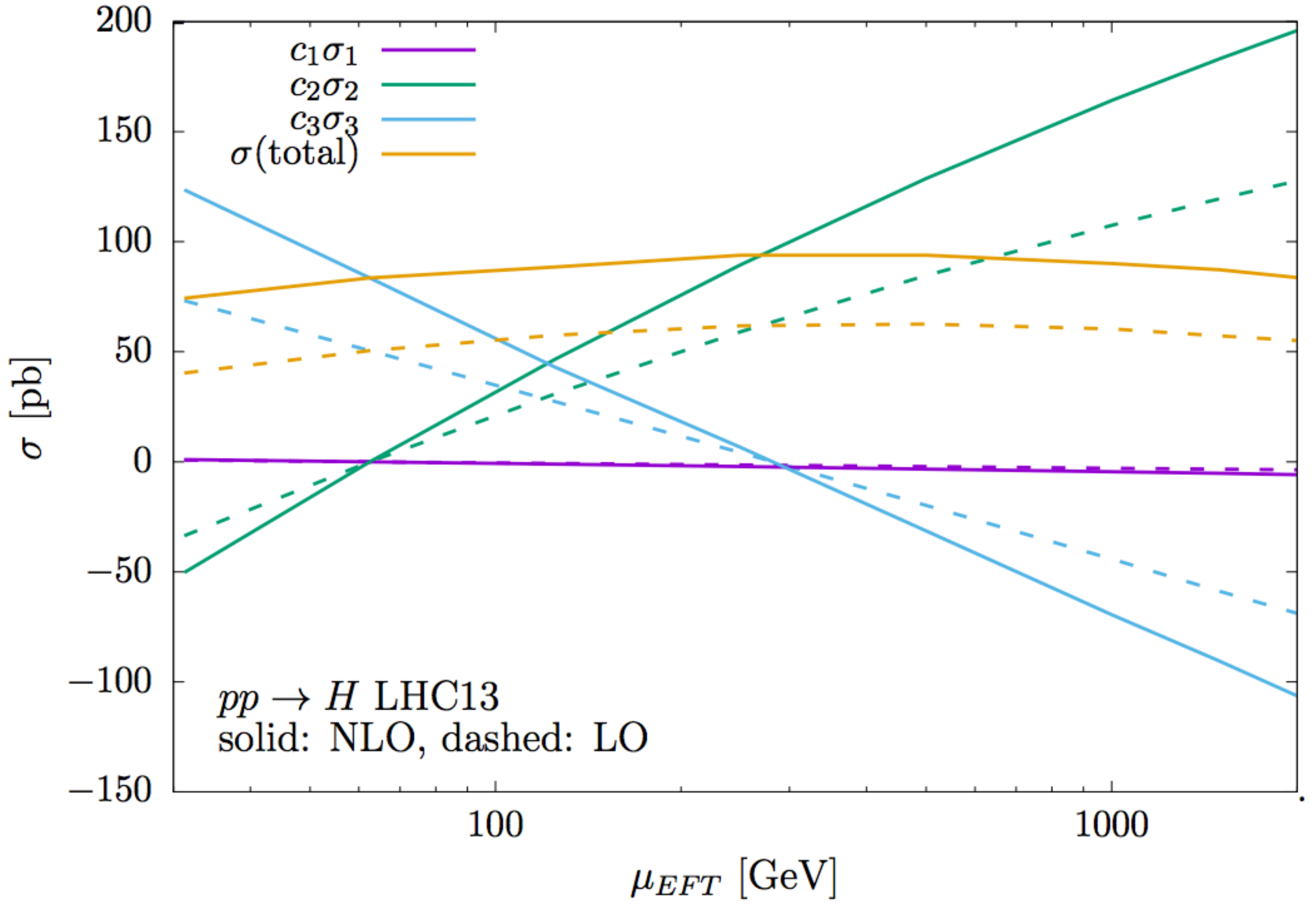
Degrande, Maltoni, Mimasu, EV, Zhang arXiv:1804.07773

Accuracy and precision

Reduction of scale uncertainty

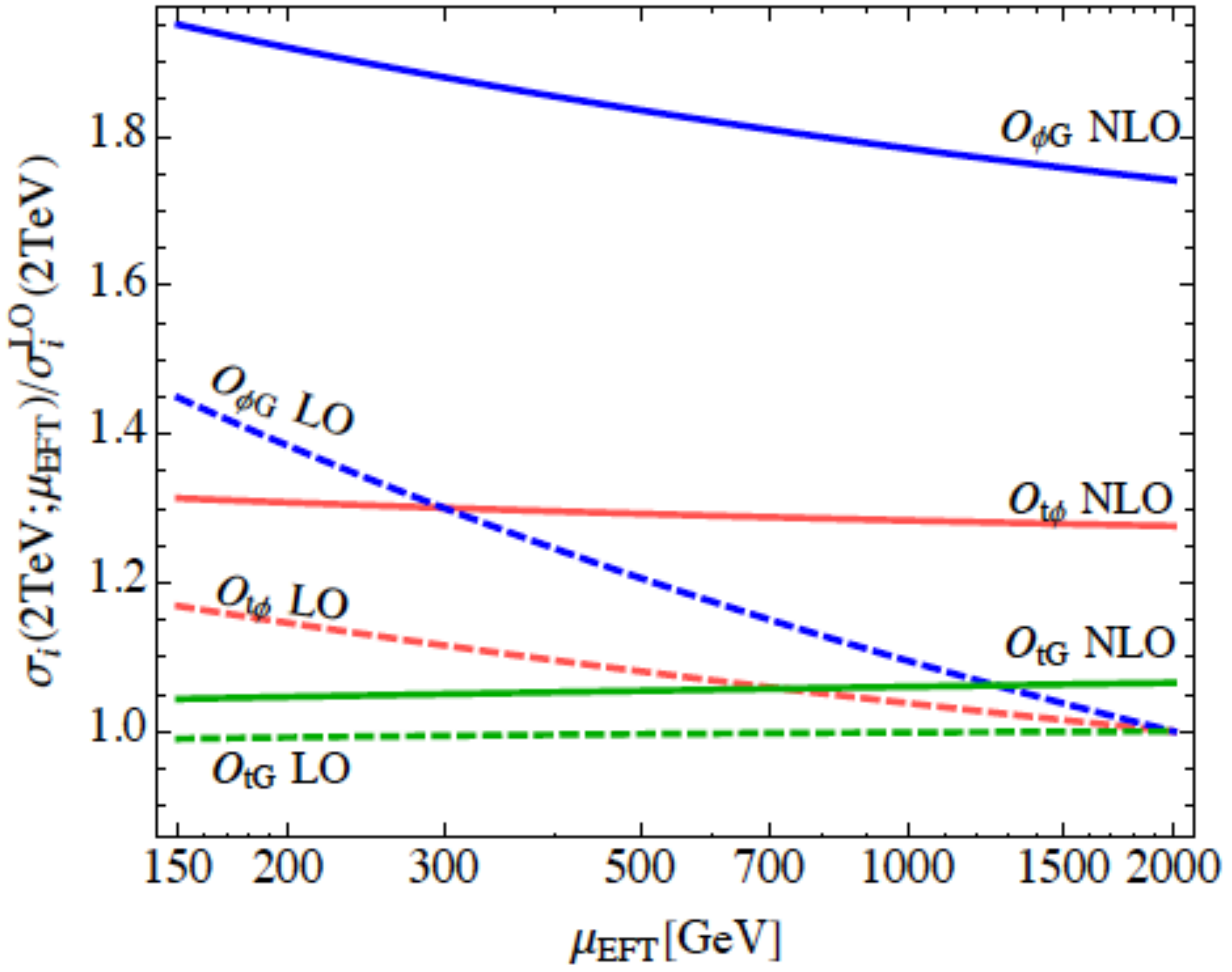
ggH





Deutschmann, Duhr, Maltoni, EV arXiv:1708.00460

ttH



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

Maltoni, EV, Zhang arXiv:1607.05330

Improved sensitivity

New operators opening up at NLO

4-heavy operators in top pair production

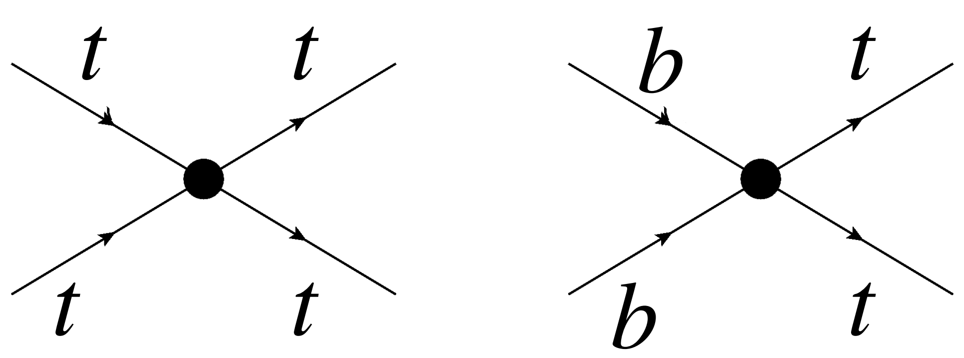
$$\mathcal{O}^{8}_{QQ} = (\bar{Q}\gamma^{\mu}T^{A}Q)(\bar{Q}\gamma_{\mu}T^{A}Q)$$

$$\mathcal{O}^{1}_{QQ} = (\bar{Q}\gamma^{\mu}Q)(\bar{Q}\gamma_{\mu}Q)$$

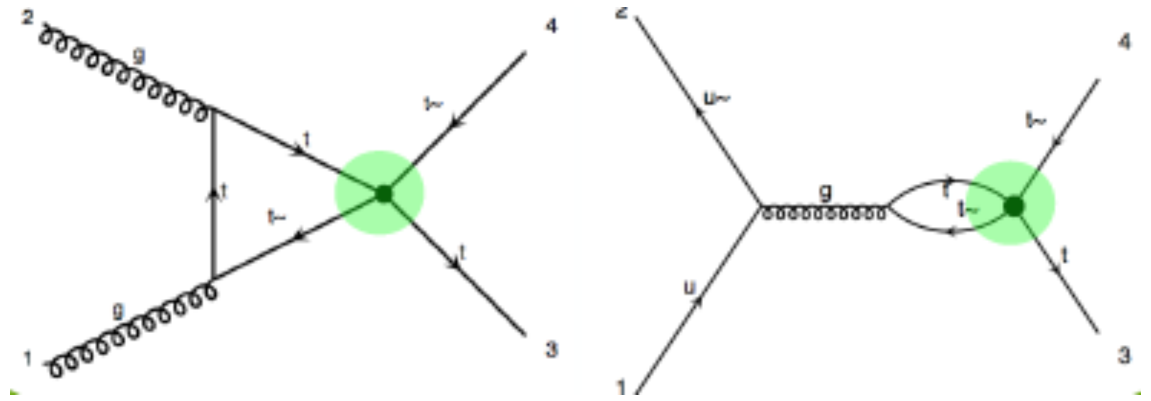
$$\mathcal{O}^{8}_{Qt} = (\bar{Q}\gamma^{\mu}T^{A}Q)(\bar{t}\gamma_{\mu}T^{A}t)$$

$$\mathcal{O}^{1}_{Qt} = (\bar{Q}\gamma^{\mu}Q)(\bar{t}\gamma_{\mu}t)$$

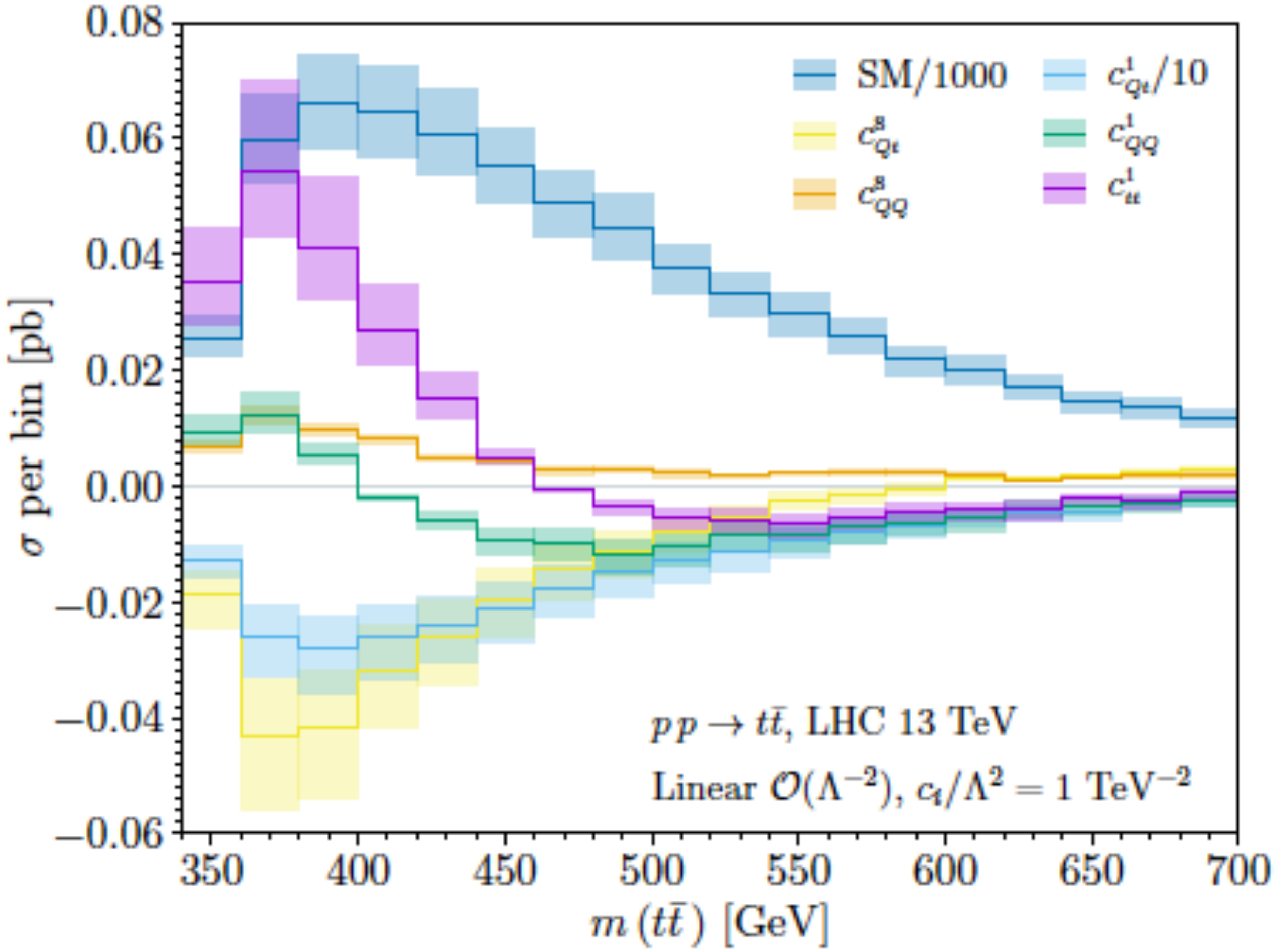
$$\mathcal{O}^{1}_{tt} = (\bar{t}\gamma^{\mu}t)(\bar{t}\gamma_{\mu}t)$$



At NLO:



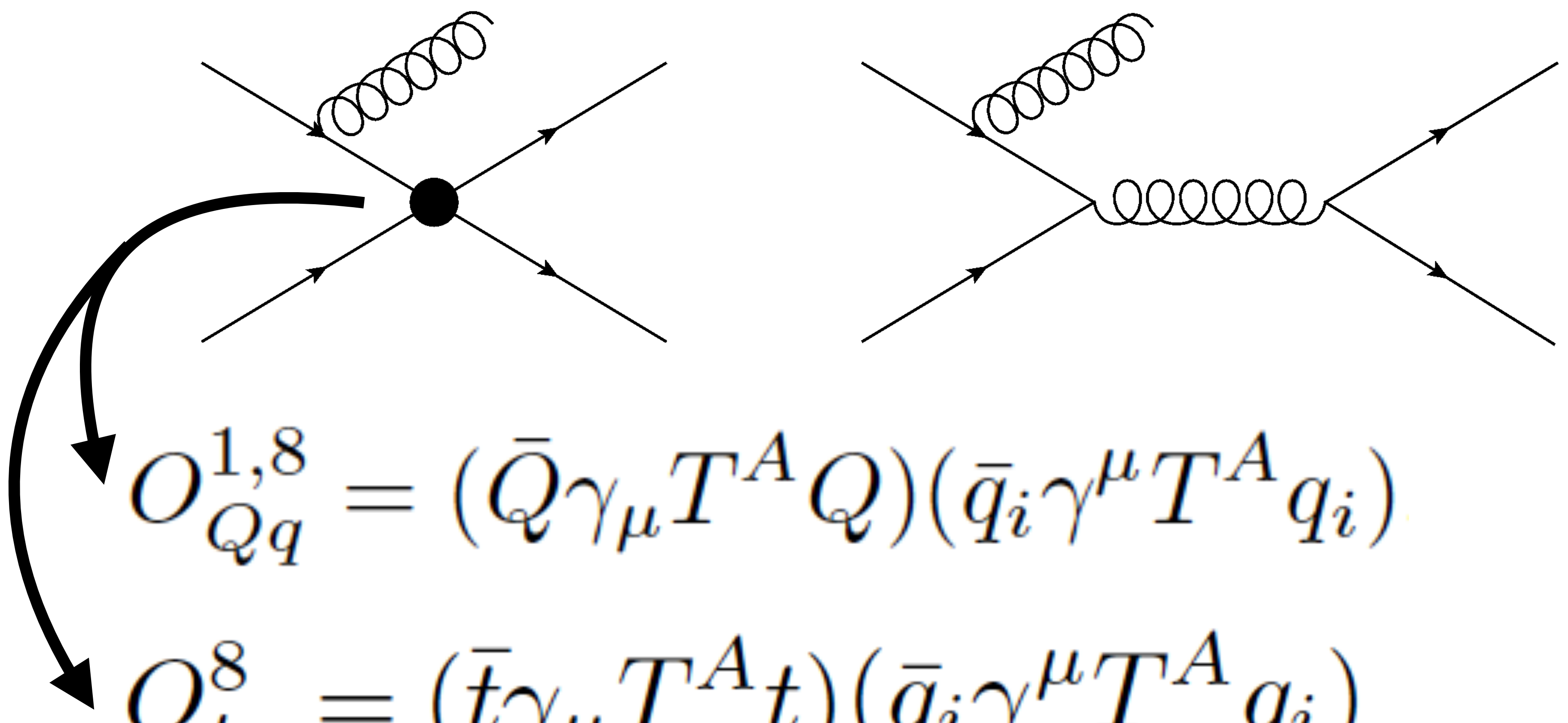
c^{8}_{QQ}	$0.0586^{+27\%}_{-25\%}$	$0.125^{+10\%}_{-11\%}$		$0.00628^{+13\%}_{-16\%}$	$0.0133^{+7\%}_{-5\%}$
c^{8}_{Qt}	$0.0583^{+27\%}_{-25\%}$	$-0.107(6)^{+40\%}_{-33\%}$		$0.00619^{+13\%}_{-16\%}$	$0.0118^{+8\%}_{-5\%}$
c^{1}_{QQ}	$[-0.11^{+15\%}_{-18\%}]$	$-0.039(4)^{+51\%}_{-33\%}$	$[-0.12^{+7\%}_{-5\%}]$	$0.0282^{+13\%}_{-16\%}$	$0.0651^{+5\%}_{-6\%}$
c^{1}_{Qt}	$[-0.068^{+16\%}_{-18\%}]$	$-2.51^{+29\%}_{-21\%}$	$[-0.12^{+3\%}_{-6\%}]$	$0.0283^{+13\%}_{-16\%}$	$0.066^{+5\%}_{-6\%}$
c^{1}_{tt}	×	$0.215^{+23\%}_{-18\%}$		×	×



Complimentary information to ttbb and 4top production

Improved sensitivity

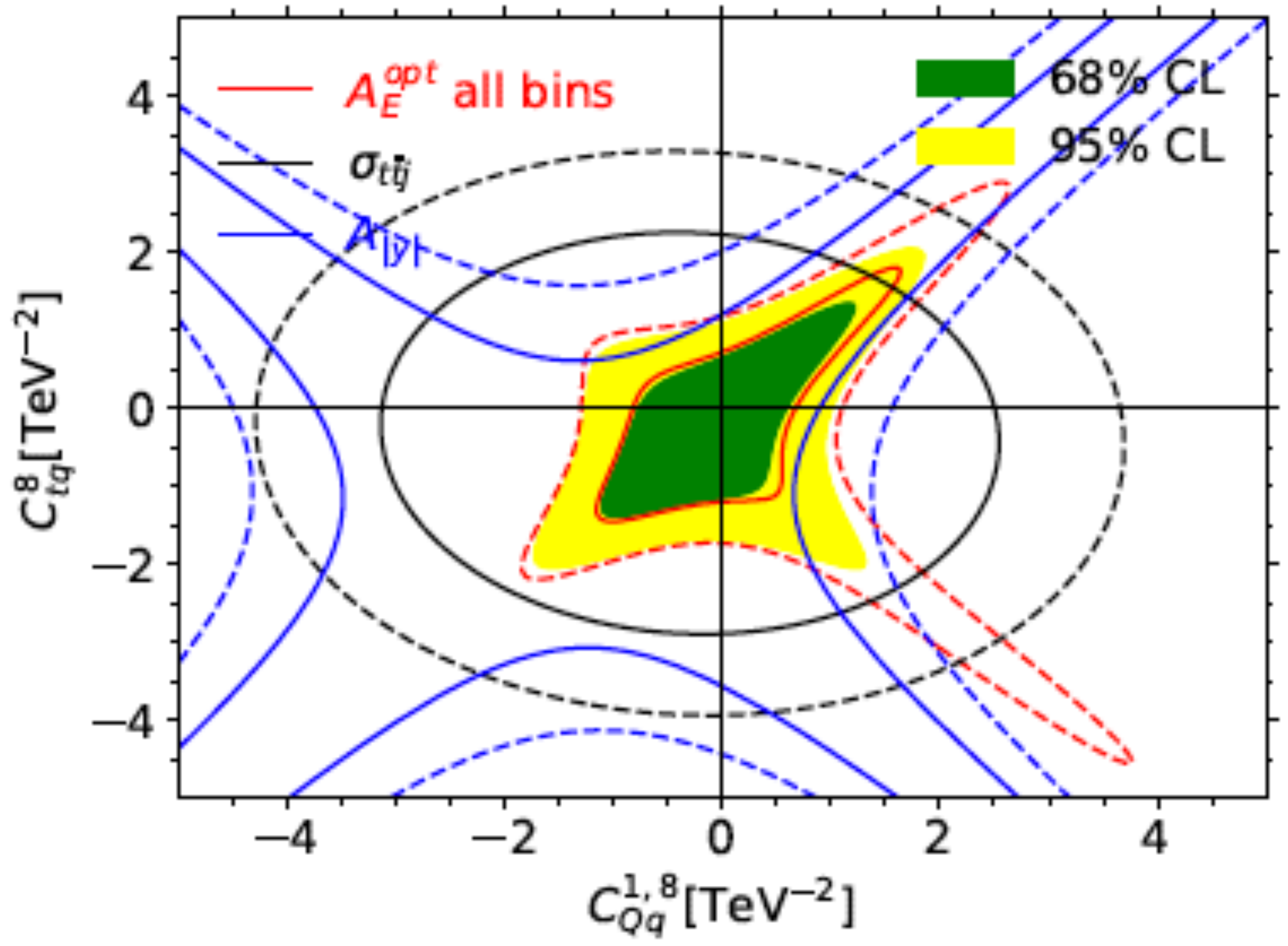
Breaking degeneracies by going beyond LO



$$O^{1,8}_{Qq} = (\bar{Q}\gamma_\mu T^A Q)(\bar{q}_i \gamma^\mu T^A q_i)$$

$$O^{8}_{tq} = (\bar{t}\gamma_\mu T^A t)(\bar{q}_i \gamma^\mu T^A q_i)$$

Different top chiralities



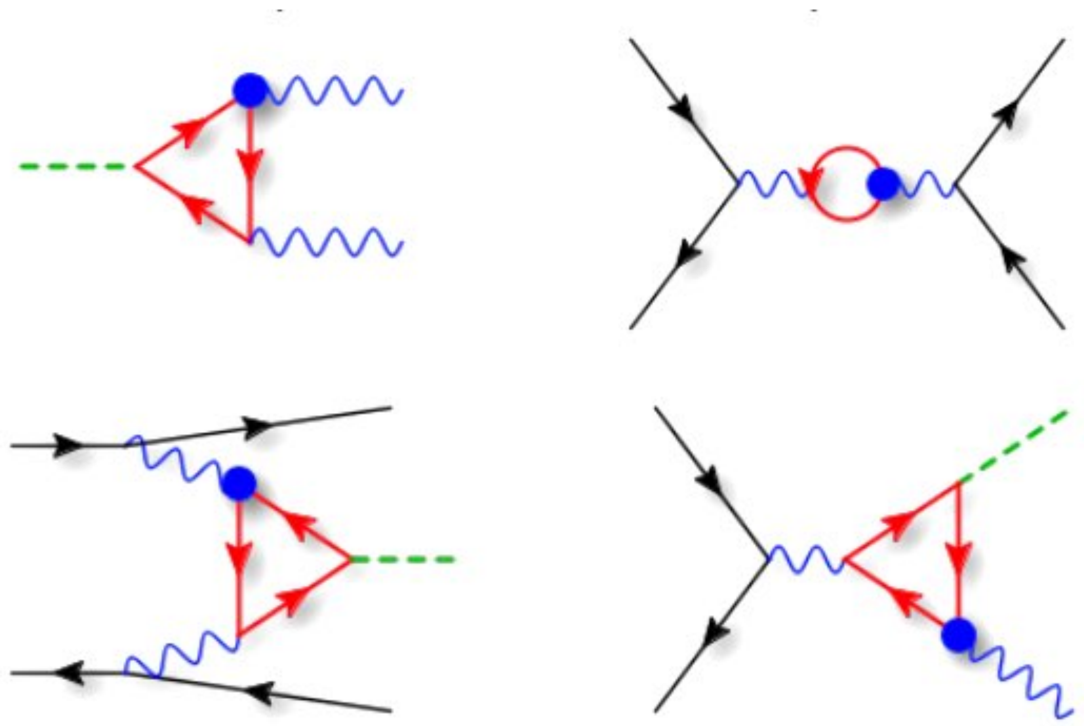
Basan, Berta, Masetti, EV, Westhoff arXiv:2001.07225

An asymmetry observable

$$A_E(\theta_j) = \frac{\sigma_{t\bar{t}j}(\theta_j, \Delta E > 0) - \sigma_{t\bar{t}j}(\theta_j, \Delta E < 0)}{\sigma_{t\bar{t}j}(\theta_j, \Delta E > 0) + \sigma_{t\bar{t}j}(\theta_j, \Delta E < 0)}$$

Loop-induced sensitivity

Top operators in Higgs observables



+

$$O_{t\varphi} = \bar{Q}t\tilde{\varphi}\,(\varphi^\dagger\varphi) + h.c.,$$
$$O^{(3)}_{\varphi Q} = (\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{Q}\gamma^\mu\tau^I Q),$$
$$O_{\varphi tb} = (\tilde{\varphi}^\dagger iD_\mu\varphi)(\bar{t}\gamma^\mu b) + h.c.,$$
$$O_{tB} = (\bar{Q}\sigma^{\mu\nu}t)\,\tilde{\varphi}B_{\mu\nu} + h.c.,$$
$$O_{\varphi t} = (\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{t}\gamma^\mu t),$$
$$O^{(1)}_{\varphi Q} = (\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{Q}\gamma^\mu Q),$$
$$O_{tW} = (\bar{Q}\sigma^{\mu\nu}\tau^I t)\,\tilde{\varphi}W^I_{\mu\nu} + h.c.,$$

+ **Relatively loose constraints from top LHC measurements (tZ, ttZ, tj, …)**

	$\gamma\gamma$	γZ	bb	WW*	ZZ*
gg	(-100%,1980%)	(-88%,200%)	(-40%,48%)	(-40%,47%)	(-40%,46%)
VBF	(-100%,1880%)	(-88%,170%)	(-6.1%,5.3%)	(-6.8%,6.7%)	(-8.8%,9.2%)
WH	(-100%,1880%)	(-88%,170%)	(-5.5%,4.2%)	(-6.1%,5.6%)	(-7.8%,7.9%)
ZH	(-100%,1880%)	(-87%,170%)	(-6.5%,5.9%)	(-7.1%,7.1%)	(-9.4%,9.9%)

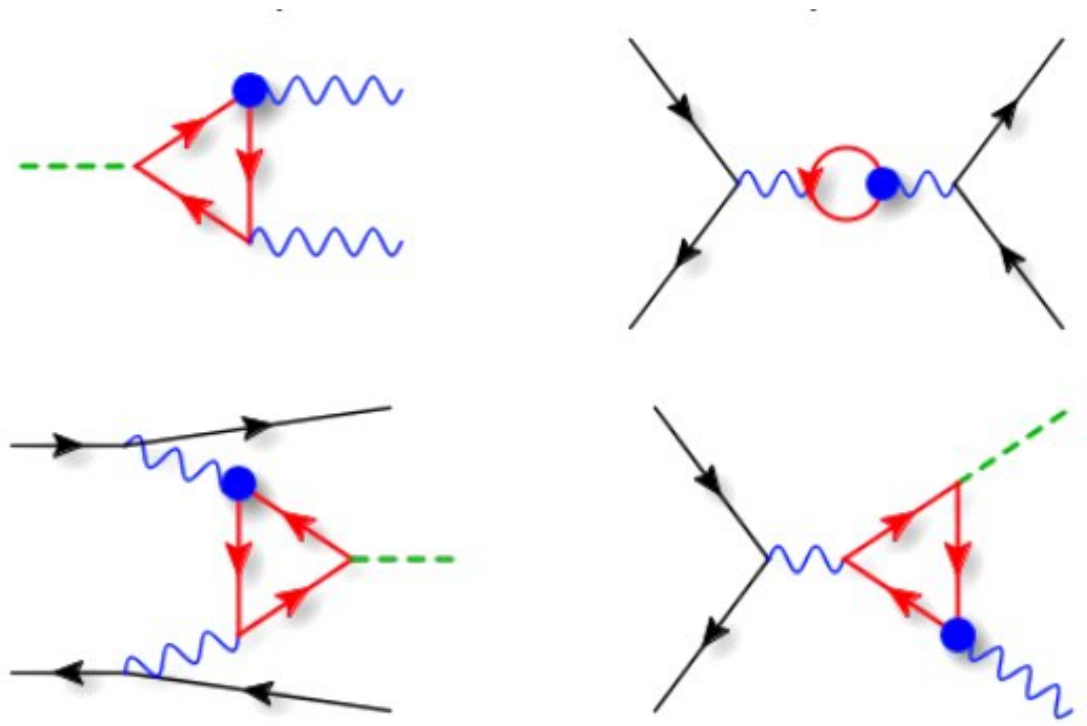
loop-induced   tree-level

EV, Zhang arXiv:1804.09766

Poor knowledge of top couplings leads to uncertainties on Higgs measurements at the LHC

Loop-induced sensitivity

Top operators in Higgs observables



+

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$$O_{tB} = (\bar{Q}\sigma^{\mu\nu}t)\,\tilde{\varphi}B_{\mu\nu} + h.c.,$$
$$O_{\varphi t} = (\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{t}\gamma^\mu t),$$
$$O^{(1)}_{\varphi Q} = (\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{Q}\gamma^\mu Q),$$
$$O_{tW} = (\bar{Q}\sigma^{\mu\nu}\tau^I t)\,\tilde{\varphi}W^I_{\mu\nu} + h.c.,$$

+ **Relatively loose constraints from top LHC measurements (tZ, ttZ, tj, …)**

→

	$\gamma\gamma$	γZ	bb	WW*	ZZ*
gg	(-100%,1980%)	(-88%,200%)	(-40%,48%)	(-40%,47%)	(-40%,46%)
VBF	(-100%,1880%)	(-88%,170%)	(-6.1%,5.3%)	(-6.8%,6.7%)	(-8.8%,9.2%)
WH	(-100%,1880%)	(-88%,170%)	(-5.5%,4.2%)	(-6.1%,5.6%)	(-7.8%,7.9%)
ZH	(-100%,1880%)	(-87%,170%)	(-6.5%,5.9%)	(-7.1%,7.1%)	(-9.4%,9.9%)

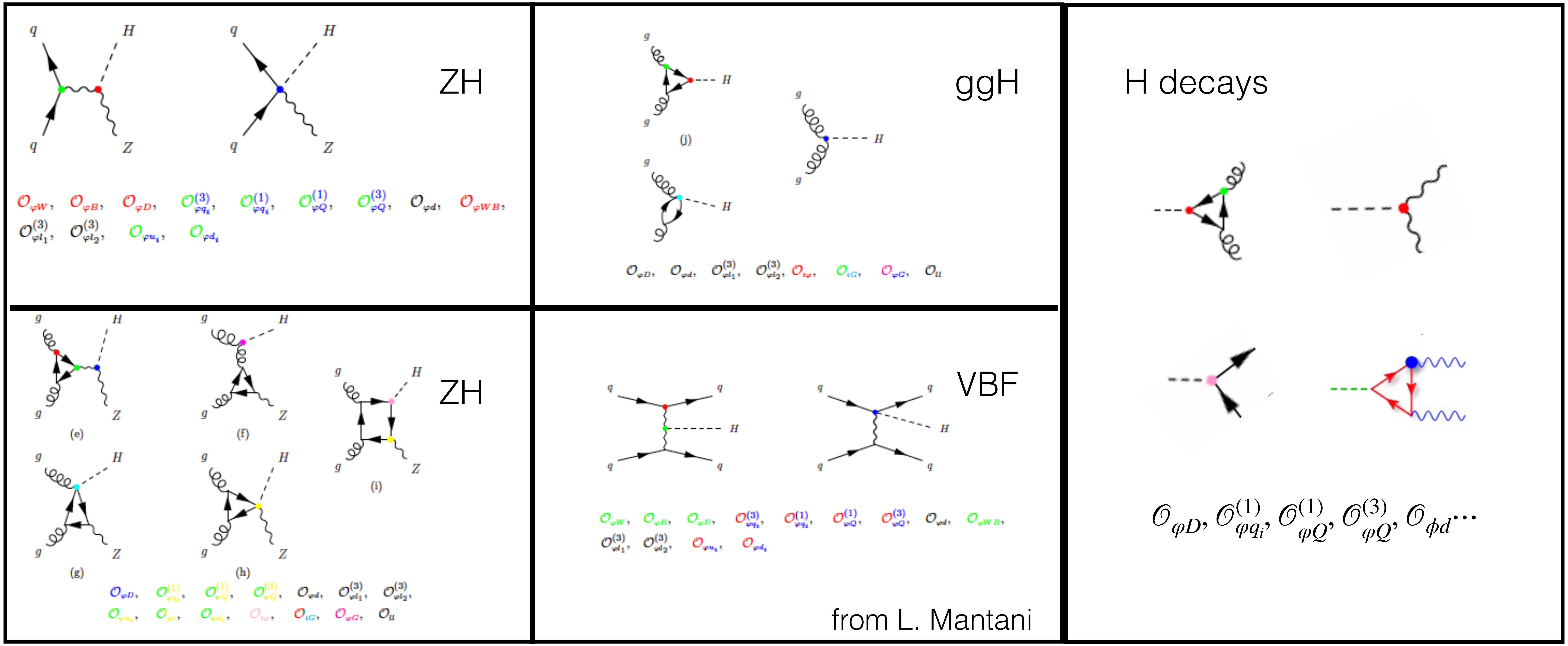
loop-induced — tree-level

EV, Zhang arXiv:1804.09766

Or… maybe one should use Higgs measurements to bound top couplings?

Loop & tree interplay

Higgs production and decay



Global Higgs-top fit

PRELIMINARY

Higgs data

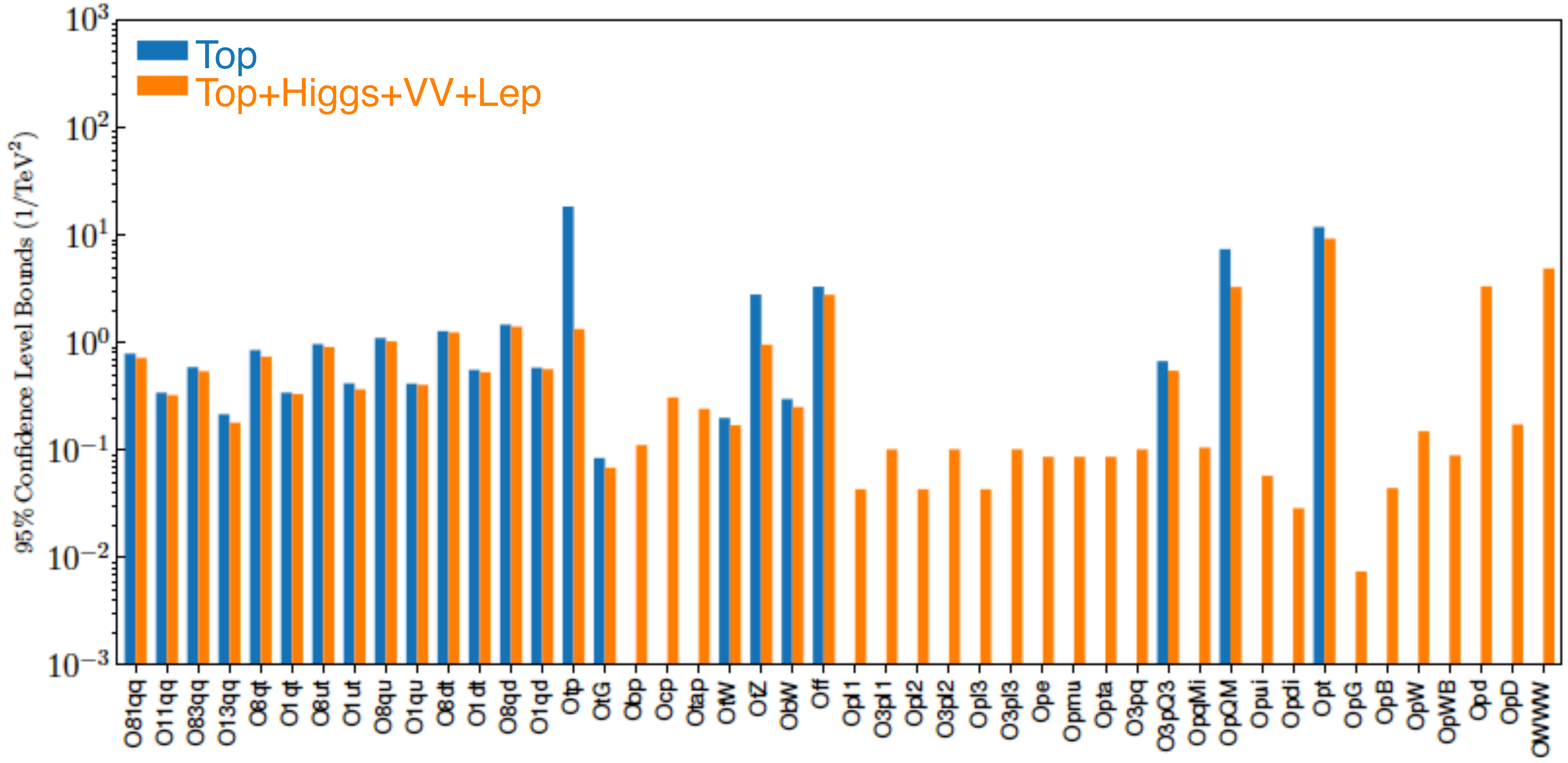
Run I & 2 signal strengths (CMS+ATLAS):
* gluon fusion
* VH
* VBF
* ttH
* H decays

Differential distributions & STXS

Top data

Run I & 2 results (CMS+ATLAS):
* pair production
* tt+V, tttt, ttbb
* single top
* tZj
* W helicity fractions

Cross-sections & Differential distributions



Ethier, Maltoni, Mantani, Nocera, Rojo, EV and Zhang in preparation

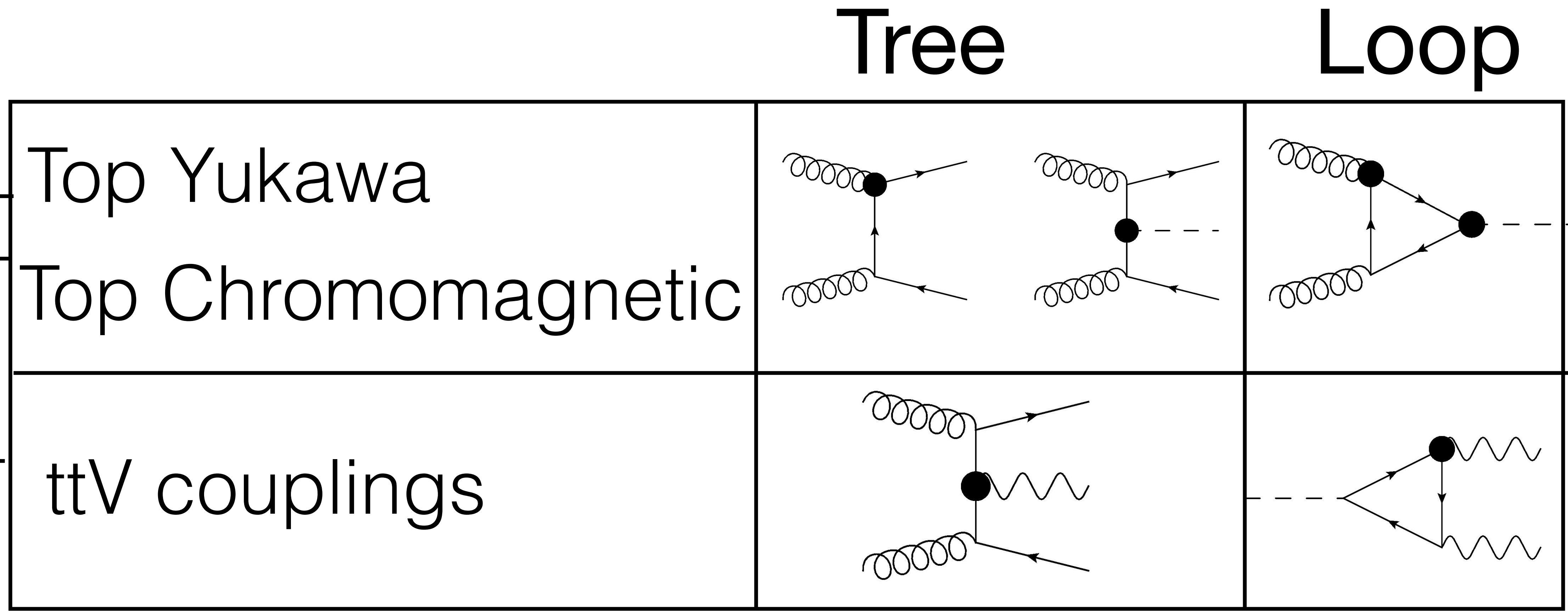
Global Higgs-top fit

Fisher Information

		Processes							
Class	Coefficient	tt	ttV	t	tV	Hrun1	Hrun2	Hdiff	VV
2L2H	O81qq	81.7(96.0)	16.4(2.4)	×(×)	×(×)	0.1(-0.0)	1.7(0.8)	0.1(0.7)	×(×)
	O11qq	100.0(98.8)	0.0(0.5)	×(×)	×(×)	×(0.0)	0.0(0.6)	×(0.2)	×(×)
	O83qq	48.3(46.2)	25.9(50.6)	23.9(2.6)	0.0(0.3)	0.1(-0.0)	1.7(0.2)	0.1(0.1)	×(×)
	O13qq	0.4(13.8)	0.0(1.2)	96.5(82.7)	3.1(2.1)	×(-0.1)	0.0(0.1)	×(0.2)	×(×)
	O8qt	56.1(47.0)	38.9(31.4)	×(×)	×(×)	0.3(0.2)	4.5(12.2)	0.2(9.2)	×(×)
	O1qt	100.0(94.6)	0.0(3.3)	×(×)	×(×)	×(0.0)	0.0(1.7)	×(0.4)	×(×)
	O8ut	97.7(97.9)	0.4(0.3)	×(×)	×(×)	0.1(0.0)	1.7(0.8)	0.1(0.9)	×(×)
	O1ut	100.0(98.3)	0.0(0.3)	×(×)	×(×)	×(0.0)	0.0(1.1)	×(0.3)	×(×)
	O8qu	88.8(80.1)	3.6(5.2)	×(×)	×(×)	0.4(0.1)	6.8(8.3)	0.4(6.2)	×(×)
	O1qu	100.0(97.9)	0.0(0.7)	×(×)	×(×)	×(0.0)	0.0(1.1)	×(0.3)	×(×)
	O8dt	95.0(97.9)	1.4(0.7)	×(×)	×(×)	0.2(0.0)	3.3(0.9)	0.2(0.5)	×(×)
	O1dt	100.0(98.9)	0.0(0.2)	×(×)	×(×)	×(0.0)	0.0(0.7)	×(0.2)	×(×)
	O8qd	94.3(69.0)	2.6(9.5)	×(×)	×(×)	0.1(0.3)	2.8(12.6)	0.1(8.6)	×(×)
	O1qd	100.0(97.6)	0.0(1.0)	×(×)	×(×)	×(0.0)	0.0(1.2)	×(0.2)	×(×)
2FB	Otp	×(×)	×(×)	×(×)	×(×)	13.7(18.6)	46.2(67.9)	40.1(13.4)	×(×)
	OtG	61.1(23.2)	0.2(0.1)	×(×)	×(×)	5.9(10.4)	17.5(29.5)	15.2(36.8)	×(×)
	Obp	×(×)	×(×)	×(×)	×(×)	26.6(26.8)	73.4(73.2)	×(×)	×(×)
	Ocp	×(×)	×(×)	×(×)	×(×)	26.8(26.3)	73.2(73.7)	×(×)	×(×)
	Otap	×(×)	×(×)	×(×)	×(×)	39.1(38.5)	60.9(61.5)	×(×)	×(×)
	OtW	9.1(0.4)	0.0(0.0)	0.4(0.0)	0.2(0.0)	18.9(20.8)	71.5(78.7)	×(×)	×(×)
	OtZ	×(×)	0.0(0.0)	×(×)	0.0(0.0)	21.0(21.0)	79.0(79.0)	×(×)	×(×)
	O3pQ3	×(0.0)	0.0(0.0)	80.0(4.7)	14.3(0.8)	1.2(18.2)	4.5(76.1)	0.0(0.1)	×(×)
	OpQM	×(×)	41.8(0.0)	×(×)	0.6(0.0)	11.9(20.0)	45.7(79.9)	0.0(0.0)	×(×)
	Opt	×(×)	64.5(0.0)	×(×)	0.2(0.0)	7.4(21.0)	27.9(79.0)	0.0(0.0)	×(×)
B	OpG	×(×)	×(×)	×(×)	×(×)	15.3(15.5)	42.9(42.3)	41.8(42.2)	×(×)
	OpB	×(×)	×(×)	×(×)	×(×)	21.0(21.0)	79.0(79.0)	0.0(0.0)	×(×)
	OpW	×(×)	×(×)	×(×)	×(×)	21.0(21.1)	78.9(78.9)	0.0(0.0)	×(×)
	Opd	×(×)	×(×)	×(×)	×(×)	25.4(27.4)	67.2(72.6)	7.4(0.0)	×(×)
	OWWW	×(×)	×(×)	×(×)	×(×)	×(×)	×(×)	×(×)	100.0(100.0)
	OpWB	×(×)	×(×)	×(×)	×(×)	21.1(21.1)	78.8(78.8)	0.1(0.1)	0.0(0.0)
	OpD	×(×)	×(×)	×(×)	×(×)	21.1(21.1)	78.8(78.8)	0.1(0.1)	0.0(0.0)

PRELIMINARY

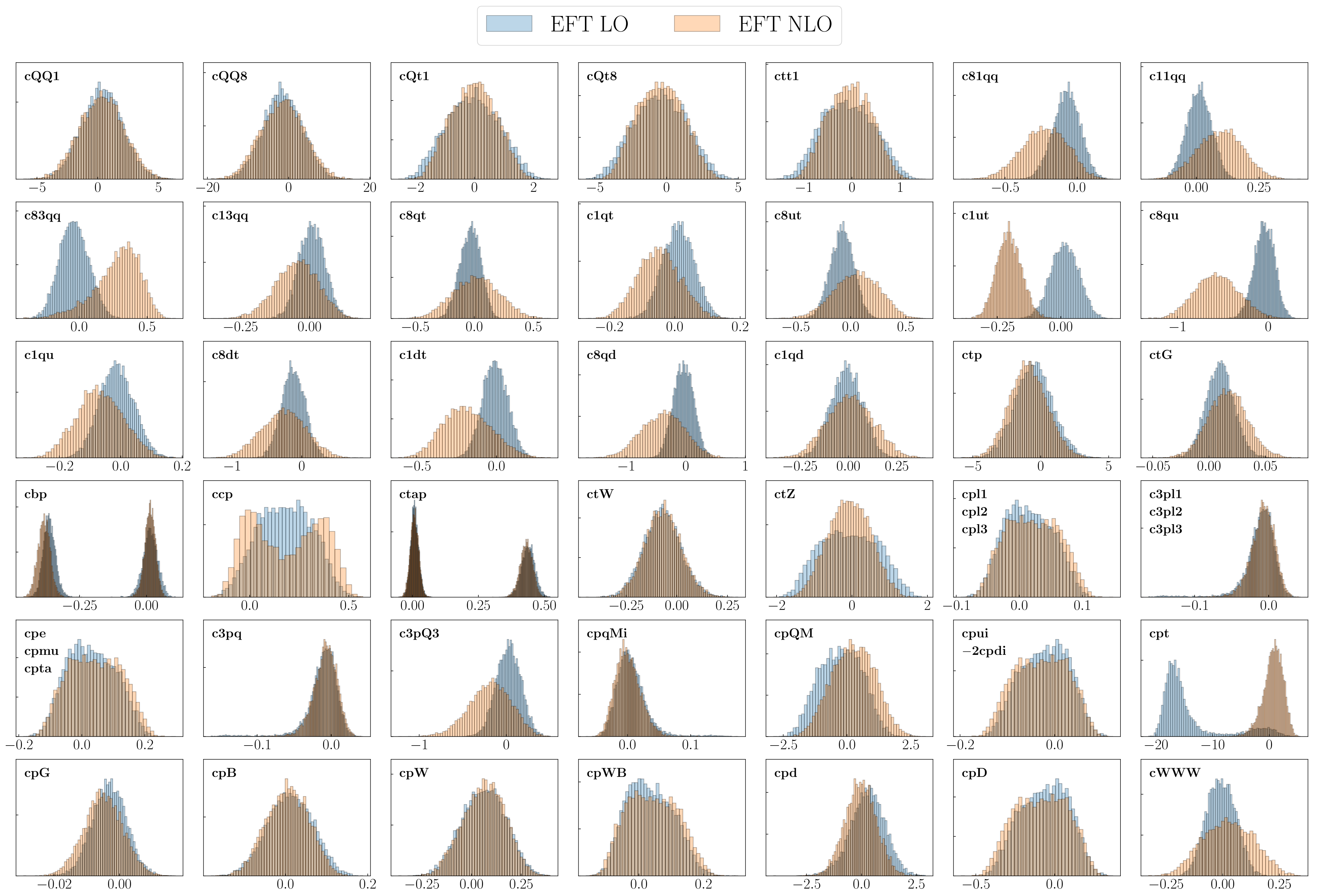
4F mostly top

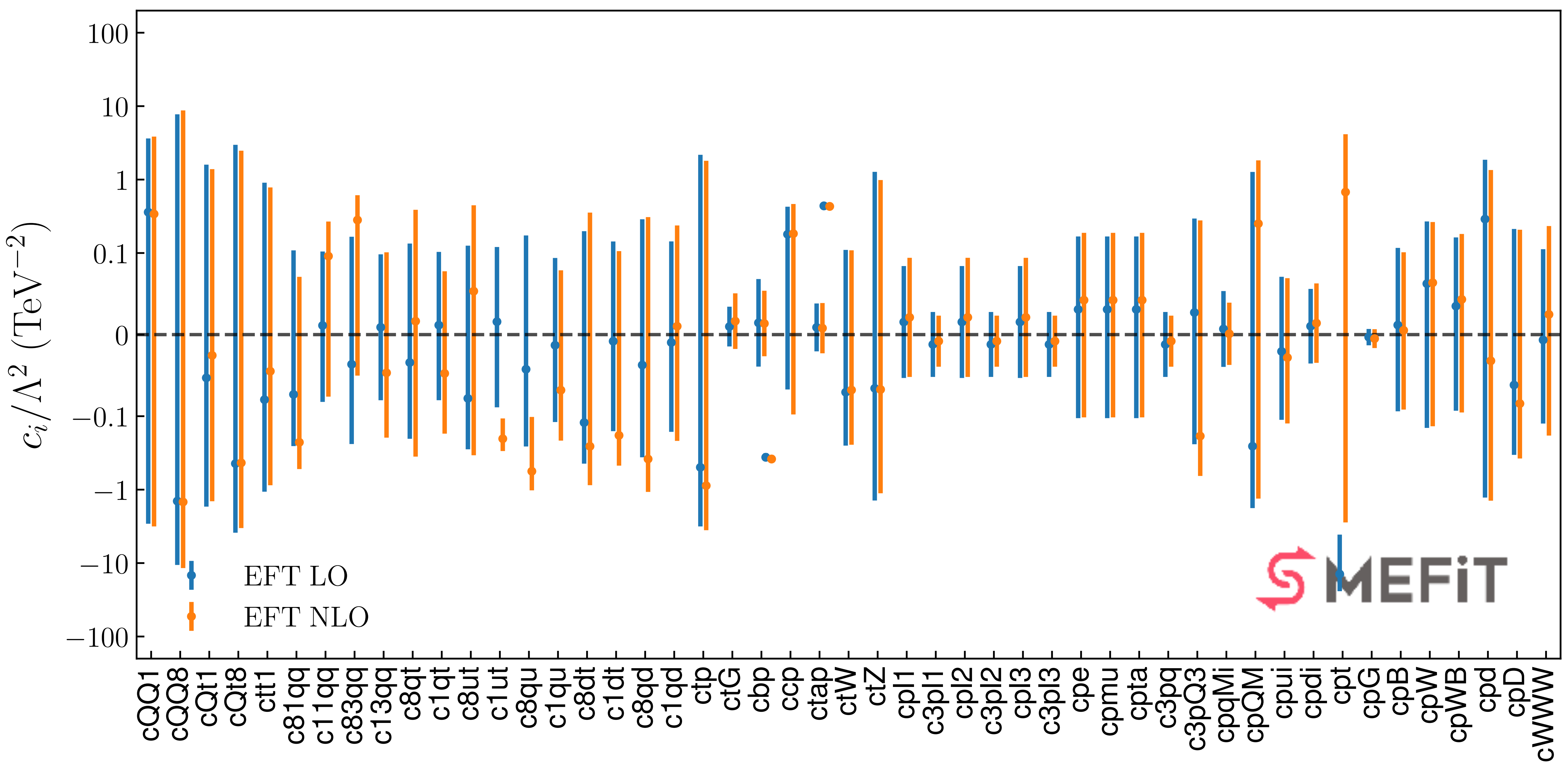


Ethier, Maltoni, Mantani, Nocera, Rojo, EV and Zhang in preparation

Impact of NLO predictions in global fits

Marginalised constraints





Posterior distributions

Significant impact of NLO for some operators

Higher orders in Monte Carlo

SMEFT@NLO

Automated one-loop computations in the SMEFT

Céline Degrande,[1,*] Gauthier Durieux,[2,†] Fabio Maltoni,[1,3,‡]
Ken Mimasu,[1,§] Eleni Vryonidou,[4,¶] and Cen Zhang[5,6,**]

We present the automation of one-loop computations in the standard-model effective field theory at dimension six. Our implementation, dubbed SMEFT@NLO, contains ultraviolet and rational counterterms for bosonic, two- and four-fermion operators. It presently allows for fully differential predictions, possibly matched to parton shower, up to one-loop accuracy in QCD. We illustrate the potential of the implementation with novel loop-induced and next-to-leading order computations relevant for top-quark, electroweak, and Higgs-boson phenomenology at the LHC and future colliders.

Degrande, Durieux, Maltoni, Mimasu, EV, Zhang
arXiv:2008.11743

Standard Model Effective Theory at One-Loop in QCD

Céline Degrande, Gauthier Durieux, Fabio Maltoni, Ken Mimasu, Eleni Vryonidou & Cen Zhang, arXiv:2008.11743

The implementation is based on the Warsaw basis of dimension-six SMEFT operators, after canonical normalization. Electroweak input parameters are taken to be G_F, M_Z, M_W. The CKM matrix is approximated as a unit matrix, and a $U(2)_q \times U(2)_u \times U(3)_d \times (U(1)_l \times U(1)_e)^3$ flavor symmetry is enforced. It forbids all fermion masses and Yukawa couplings except that only of the top quark. The model therefore implements the five-flavor scheme for PDFs.

A new coupling order, `NP=2`, is assigned to SMEFT interactions. The cutoff scale `Lambda` takes a default value of 1 TeV^{-2} and can be modified along with the Wilson coefficients in the `param_card`. Operators definitions, normalisations and coefficient names in the UFO model are specified in definitions.pdf. The notations and normalizations of top-quark operator coefficients comply with the LHC TOP WG standards of 1802.07237. Note however that the flavor symmetry enforced here is slightly more restrictive than the baseline assumption there (see the dim6top page for more information). This model has been validated at tree level against the `dim6top` implementation (see 1906.12310 and the comparison details).

Current implementation

UFO model: SMEFTatNLO_v1.0.tar.gz

- 2020/08/24 - v1.0: Official release including notably four-quark operators at NLO.

Support

Please direct any questions to smeftatnlo-dev**[at]**cern**[dot]**ch.

http://feynrules.irmp.ucl.ac.be/wiki/SMEFTatNLO

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- The Selection Committee for this award and the sponsors of this prize (Springer, World Scientific, Centro Fermi), and Guido Altarelli for his vast contributions to particle physics.
- Fabio Maltoni for his support over the years.
- My collaborators, in particular the SMEFT@NLO and MG5_aMC teams
- My PhD supervisor: James Stirling for his guidance and support during my PhD. I am grateful that I was his student.
- My family.