Higher order effects in SMEFT for the LHC

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What’s the path to NP through EFT?

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 $1/\Lambda^2$

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

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: operators entering at one-loop

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

What’s included?

Warsaw basis

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	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star \left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p d_r \varphi)$
~~$Q_{\widetilde W}$~~	~~$\varepsilon^{IJK} \widetilde W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$~~				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar l_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar l_p \gamma^\mu l_r)$
~~$Q_{\varphi\widetilde G}$~~	~~$\varphi^\dagger\varphi\, \widetilde G^A_{\mu\nu} G^{A\mu\nu}$~~	Q_{eB}	$(\bar l_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar l_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uG}	$(\bar q_p \sigma^{\mu\nu} T^A u_r)\widetilde\varphi\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar e_p \gamma^\mu e_r)$
~~$Q_{\varphi\widetilde W}$~~	~~$\varphi^\dagger\varphi\, \widetilde W^I_{\mu\nu} W^{I\mu\nu}$~~	Q_{uW}	$(\bar q_p \sigma^{\mu\nu} u_r)\tau^I \widetilde\varphi\, W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar q_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar q_p \sigma^{\mu\nu} u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar q_p \tau^I \gamma^\mu q_r)$
~~$Q_{\varphi\widetilde B}$~~	~~$\varphi^\dagger\varphi\, \widetilde B_{\mu\nu} B^{\mu\nu}$~~	Q_{dG}	$(\bar q_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar u_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar q_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar d_p \gamma^\mu d_r)$
~~$Q_{\varphi\widetilde WB}$~~	~~$\varphi^\dagger\tau^I\varphi\, \widetilde W^I_{\mu\nu} B^{\mu\nu}$~~	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}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$		

CP-even, B and flavour-conserving

Flavour assumptions

Singling out the top quark

$U(3)_L \times U(3)_e \times U(2)_Q \times U(2)_u \times U(3)_d$

- Chirality-flipping interactions involving Q3 & tR
- Chirality-conserving interactions: universal gen. 1 & 2 + 3rd gen
- Four-fermions: 2-heavy-2-light & 4-heavy (no 4-light)

Yukawa	$\psi^2 H^3 : (\varphi^\dagger \varphi)^2 (\bar{Q}\, t\, \tilde{\varphi})$
Dipoles	$\psi^2 X H : (\bar{Q}\, \sigma^{\mu\nu}\, t\, \tilde{\varphi}) B_{\mu\nu}\ [W^I_{\mu\nu},\, G^a_{\mu\nu}]$
3rd gen. currents	$\psi^2 H^2 D : (\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{Q}\, \gamma^\mu\, Q)\ [(\bar{Q}\, \gamma^\mu \tau^I\, Q),\, (\bar{t}\, \gamma^\mu\, t), \ldots]$
3rd gen. 4F	$\psi^4 : (\bar{Q}\, \gamma^\mu\, Q)(\bar{q}\, \gamma_\mu\, q),\, (\bar{Q}\, \gamma^\mu\, Q)(\bar{Q}\, \gamma_\mu\, Q), \ldots$

See also dim6top

[Aguilar-Saavedra et al. arXiv:1802.07237]

What can the code do?

Examples

Drell Yan

```
> p p > mu+ mu-        QCD=0 QED=2 NP=2 [QCD]
> p p > mu+ vm         QCD=0 QED=2 NP=2 [QCD]
> p p > W+  j  $$ t    QCD=1 QED=1 NP=2 [QCD]
> p p > W-  j  $$ t~   QCD=1 QED=1 NP=2 [QCD]
> p p > Z   j          QCD=1 QED=1 NP=2 [QCD]
```

Multi-boson production

quark-initiated

```
> p p > W+ W-    QED=2 QCD=0 NP=2 [QCD]
> p p > W+ Z     QED=2 QCD=0 NP=2 [QCD]
> p p > Z  Z     QED=2 QCD=0 NP=2 [QCD]
```

loop-induced

```
> g g > W+ W-    QED=2 QCD=2 NP=2 [QCD]
> g g > Z  Z     QED=2 QCD=2 NP=2 [QCD]
> g g > W+ W- Z  QED=3 QCD=2 NP=2 [QCD]
> g g > Z  Z  Z  QED=3 QCD=2 NP=2 [QCD]
```

Higgs production

loop-induced

```
> g g > H        QED=1 QCD=2 NP=2 [QCD]
> g g > H H      QED=2 QCD=2 NP=2 [QCD]
> g g > H H H    QED=3 QCD=2 NP=2 [QCD]
> g g > H j      QED=1 QCD=3 NP=2 [QCD]
```

Top quark production

```
> e+ e- > t t~             QED=2 QCD=0 NP=2 [QCD]
> p p > t t~               QED=0 QCD=2 NP=2 [QCD]
> p p > t t~ h             QED=1 QCD=2 NP=2 [QCD]
> p p > t t~ Z             QED=1 QCD=2 NP=2 [QCD]
> p p > t t~ W+            QED=1 QCD=2 NP=2 [QCD]
> p p > t W-      $$ t~    QED=1 QCD=1 NP=2 [QCD]
> p p > t W- j    $$ t~    QED=1 QCD=2 NP=2 [QCD]
> p p > t j       $$ W-    QED=2 QCD=0 NP=2 [QCD]
> p p > t h j     $$ W-    QED=3 QCD=0 NP=2 [QCD]
> p p > t Z j     $$ W-    QED=3 QCD=0 NP=2 [QCD]
> p p > t a j     $$ W-    QED=3 QCD=0 NP=2 [QCD]
```

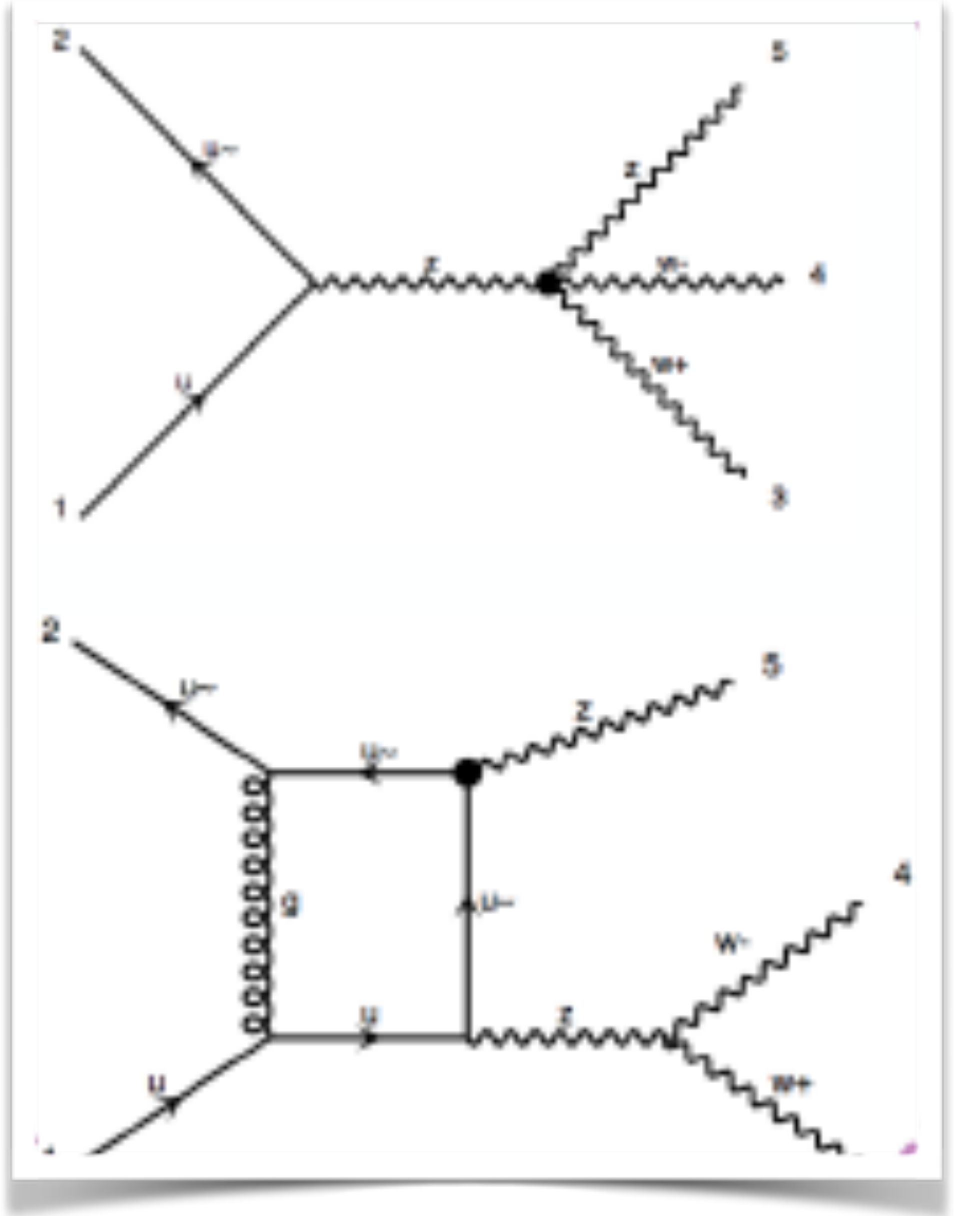
→ Including 4-fermion operators

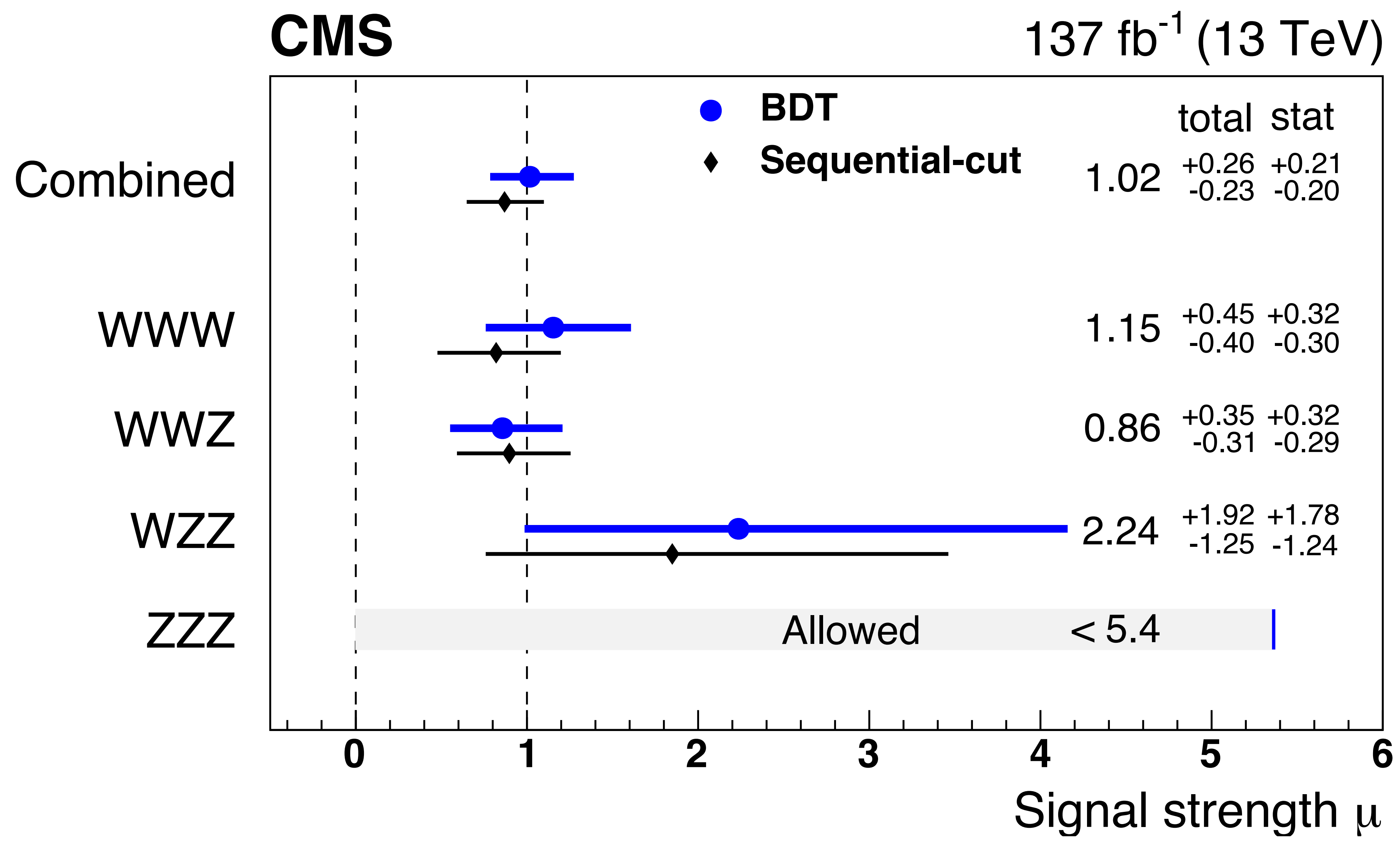
And many more…

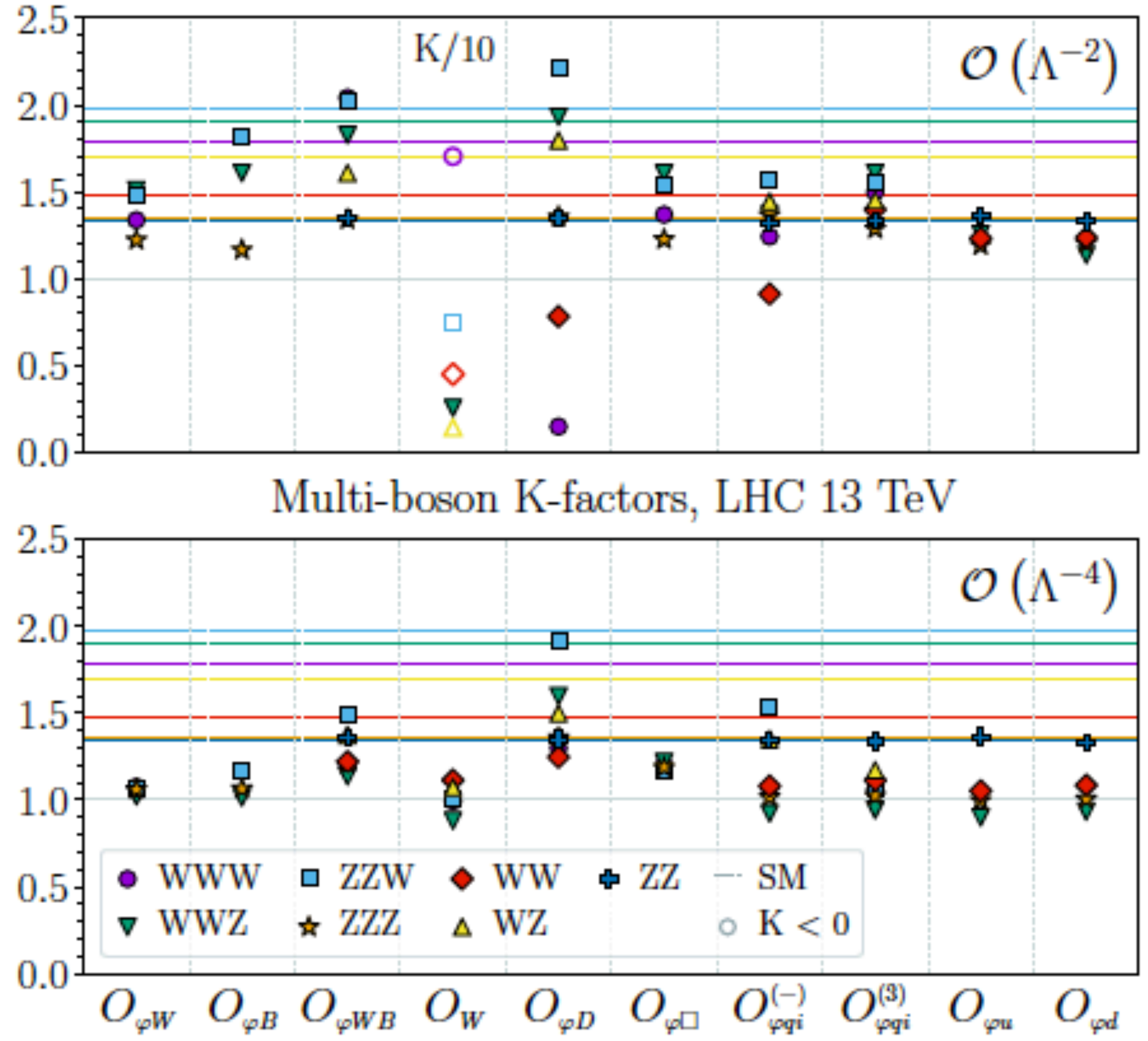
Applications at NLO

Triboson production

NEW







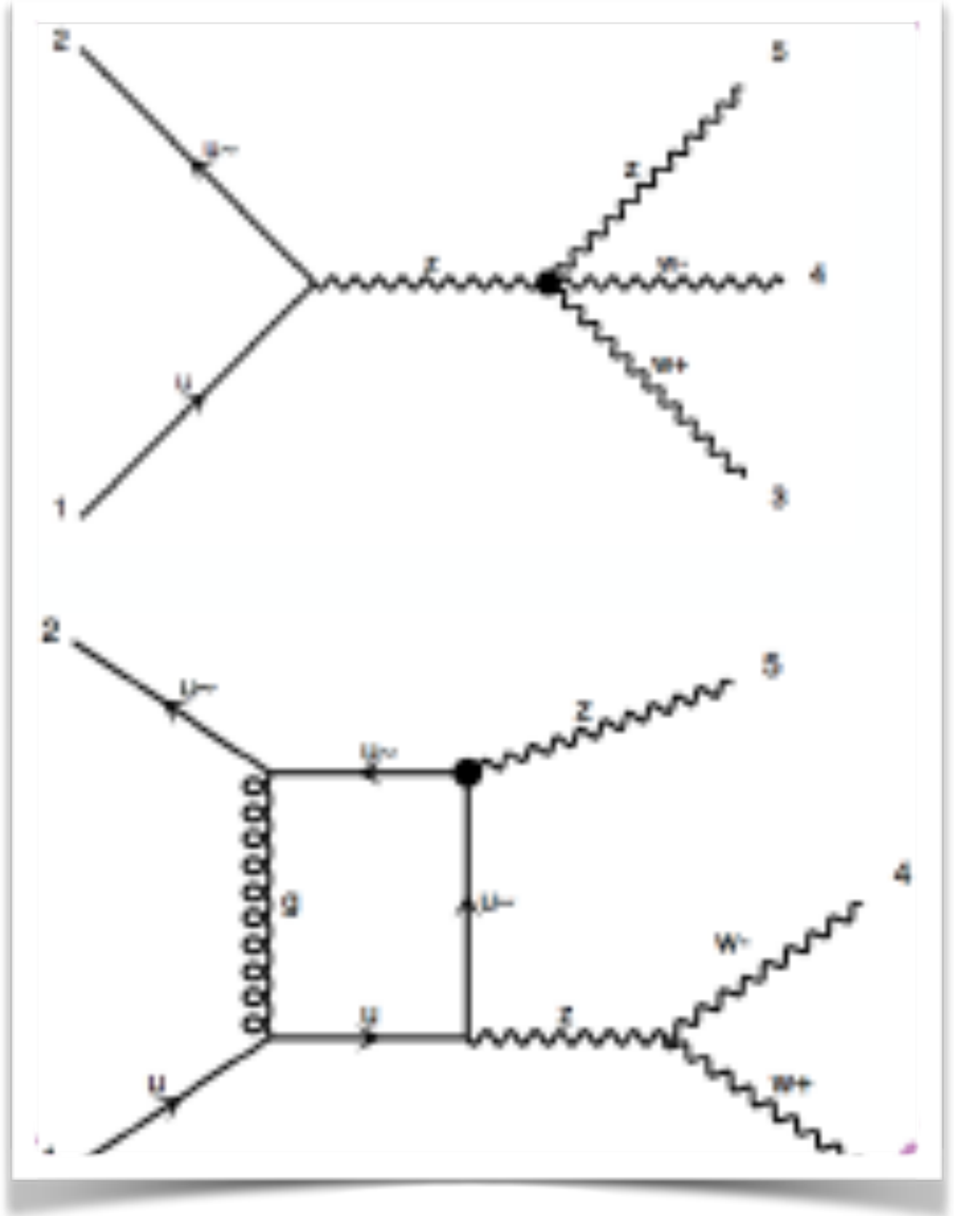
First computation of VVV@NLO in the SMEFT

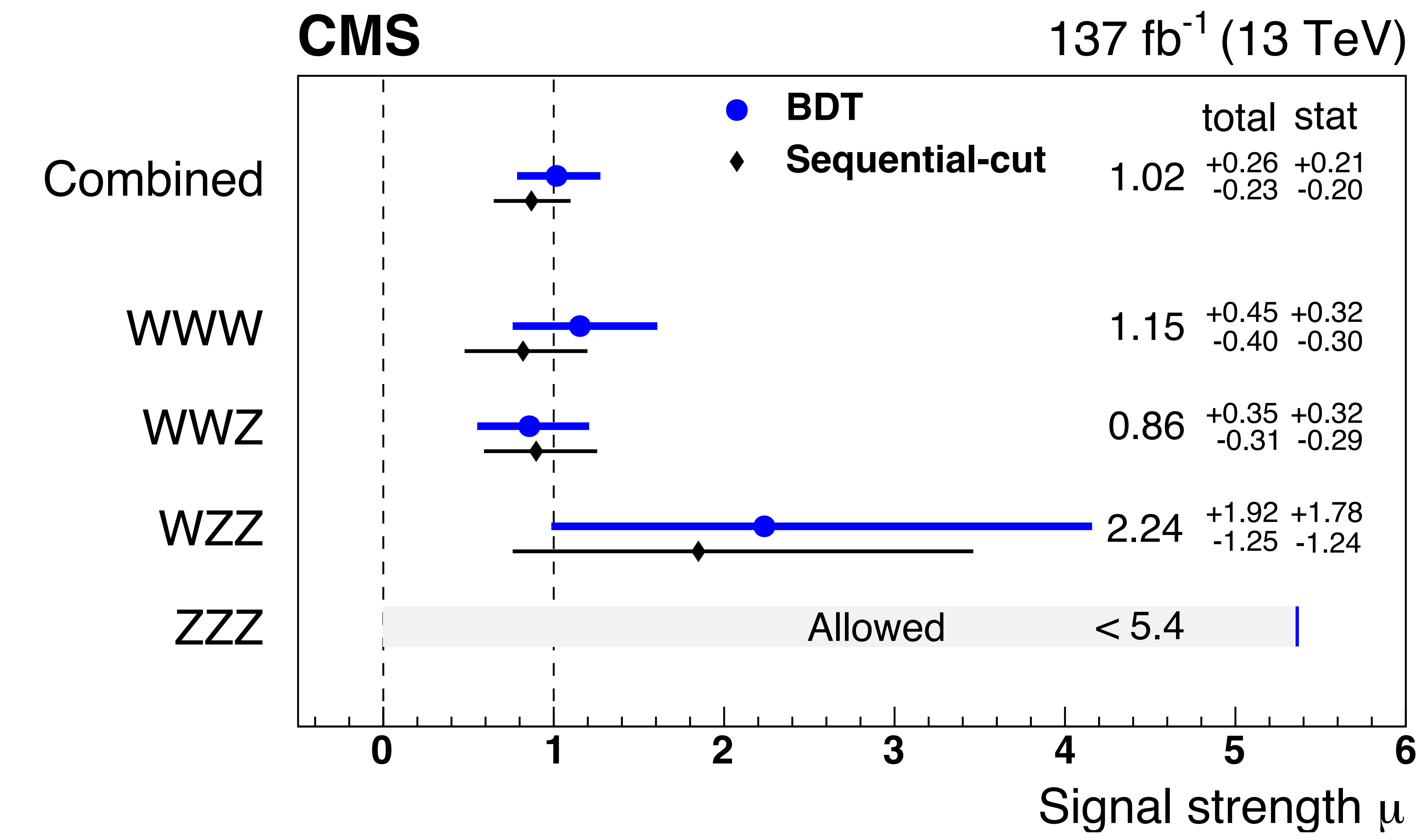
c.f. first observation by CMS: arXiv:2006.11191

Applications at NLO

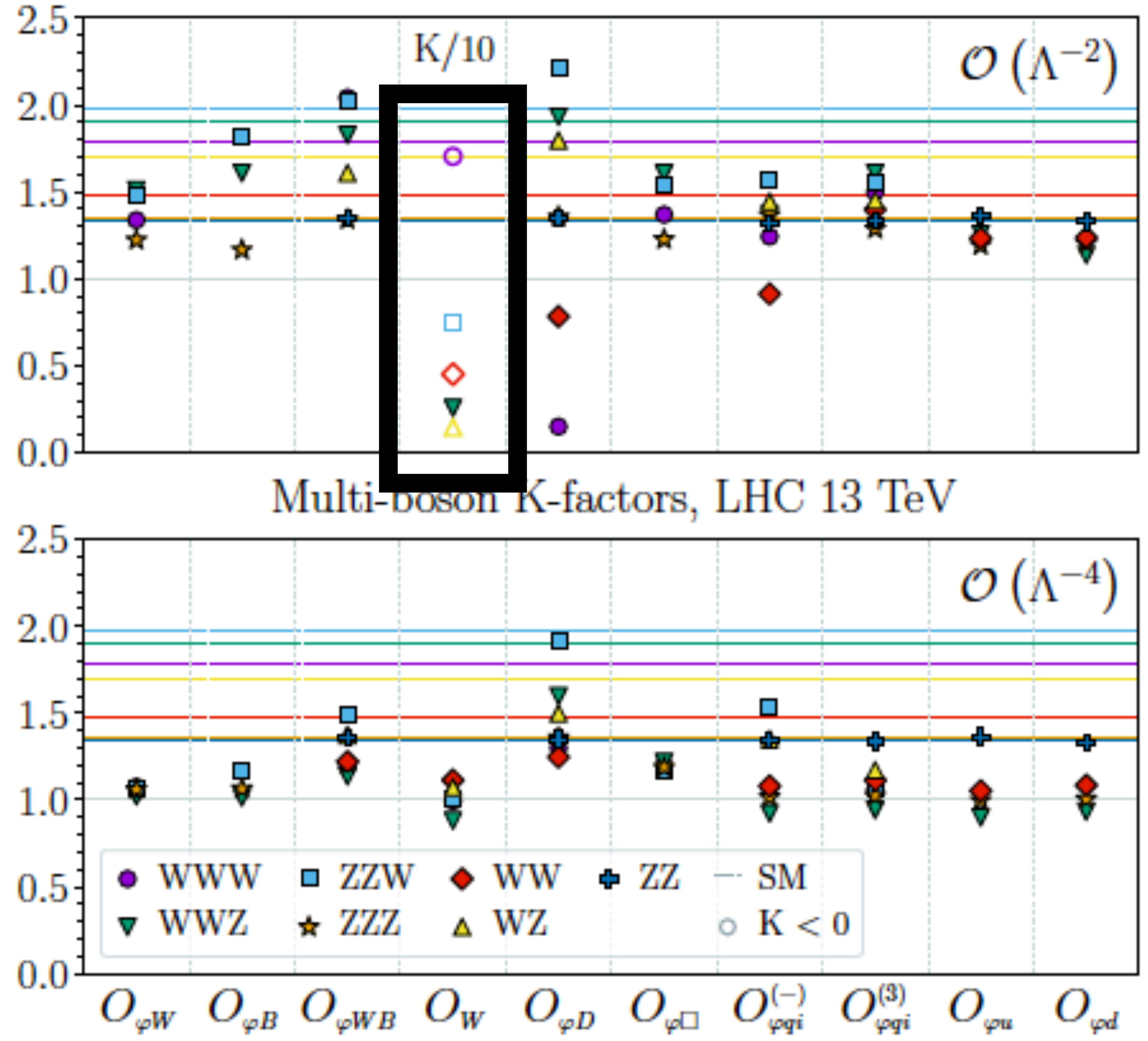
Triboson production

NEW





Interference resurrection

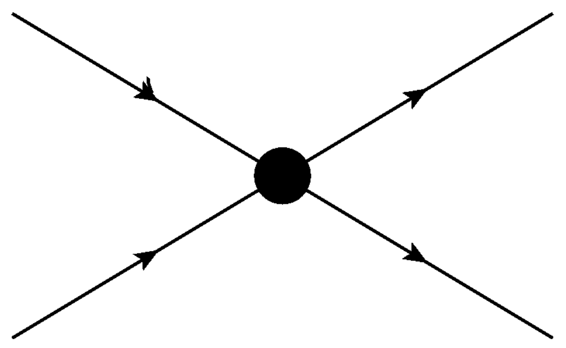
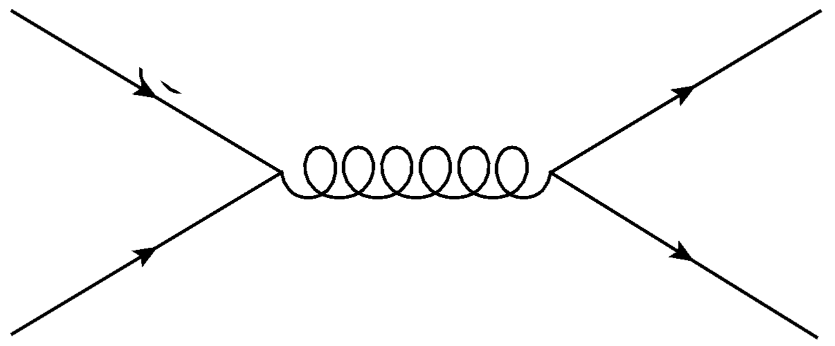


First computation of VVV@NLO in the SMEFT

c.f. first observation by CMS: arXiv:2006.11191

Applications at NLO

EFT in top pair production

EFT   SM

4-fermion operators

$$O^{1,8}_{Qq} = (\bar{Q}\gamma_\mu T^A Q)(\bar{q}_i\gamma^\mu T^A q_i) \qquad O^{1,1}_{Qq} = (\bar{Q}\gamma_\mu Q)(\bar{q}_i\gamma^\mu q_i)$$
$$O^{3,8}_{Qq} = (\bar{Q}\gamma_\mu T^A \tau^I Q)(\bar{q}_i\gamma^\mu T^A \tau^I q_i) \qquad O^{3,1}_{Qq} = (\bar{Q}\gamma_\mu \tau^I Q)(\bar{q}_i\gamma^\mu \tau^I q_i)$$
$$O^{8}_{tu} = (\bar{t}\gamma_\mu T^A t)(\bar{u}_i\gamma^\mu T^A u_i) \qquad O^{1}_{tu} = (\bar{t}\gamma_\mu t)(\bar{u}_i\gamma^\mu u_i)$$
$$O^{8}_{td} = (\bar{t}\gamma^\mu T^A t)(\bar{d}_i\gamma_\mu T^A d_i) \qquad O^{1}_{td} = (\bar{t}\gamma^\mu t)(\bar{d}_i\gamma_\mu d_i)\ ;$$
$$O^{8}_{Qu} = (\bar{Q}\gamma^\mu T^A Q)(\bar{u}_i\gamma_\mu T^A u_i) \qquad O^{1}_{Qu} = (\bar{Q}\gamma^\mu Q)(\bar{u}_i\gamma_\mu u_i)$$
$$O^{8}_{Qd} = (\bar{Q}\gamma^\mu T^A Q)(\bar{d}_i\gamma_\mu T^A d_i) \qquad O^{1}_{Qd} = (\bar{Q}\gamma^\mu Q)(\bar{d}_i\gamma_\mu d_i)$$
$$O^{8}_{tq} = (\bar{q}_i\gamma^\mu T^A q_i)(\bar{t}\gamma_\mu T^A t) \qquad O^{1}_{tq} = (\bar{q}_i\gamma^\mu q_i)(\bar{t}\gamma_\mu t)\ ;$$

Octets Singlets

Different chiralities and colour structures

c_i	$\mathcal{O}(\Lambda^{-2})$ LO	$\mathcal{O}(\Lambda^{-2})$ NLO		$\mathcal{O}(\Lambda^{-4})$ LO	$\mathcal{O}(\Lambda^{-4})$ NLO
c^8_{tu}	$4.27^{+11\%}_{-9\%}$	$4.06^{+1\%}_{-3\%}$		$1.04^{+6\%}_{-5\%}$	$1.03^{+2\%}_{-2\%}$
c^8_{td}	$2.79^{+11\%}_{-9\%}$	$2.77^{+1\%}_{-3\%}$		$0.577^{+6\%}_{-5\%}$	$0.611^{+3\%}_{-2\%}$
c^8_{tq}	$6.99^{+11\%}_{-9\%}$	$6.67^{+1\%}_{-3\%}$		$1.61^{+6\%}_{-5\%}$	$1.29^{+3\%}_{-2\%}$
c^8_{Qu}	$4.26^{+11\%}_{-9\%}$	$3.93^{+1\%}_{-4\%}$		$1.04^{+6\%}_{-5\%}$	$0.798^{+3\%}_{-3\%}$
c^8_{Qd}	$2.79^{+11\%}_{-9\%}$	$2.93^{+0\%}_{-1\%}$		$0.58^{+6\%}_{-5\%}$	$0.485^{+2\%}_{-2\%}$
$c^{8,1}_{Qq}$	$6.99^{+11\%}_{-9\%}$	$6.82^{+1\%}_{-3\%}$		$1.61^{+6\%}_{-5\%}$	$1.69^{+3\%}_{-3\%}$
$c^{8,3}_{Qq}$	$1.50^{+10\%}_{-9\%}$	$1.32^{+1\%}_{-3\%}$		$1.61^{+6\%}_{-5\%}$	$1.57^{+2\%}_{-2\%}$
c^1_{tu}	$[0.67^{+1\%}_{-1\%}]$	$-0.078(7)^{+31\%}_{-23\%}$	$[0.41^{+13\%}_{-17\%}]$	$4.66^{+6\%}_{-5\%}$	$5.92^{+6\%}_{-5\%}$
c^1_{td}	$[-0.21^{+1\%}_{-2\%}]$	$-0.306^{+30\%}_{-22\%}$	$[-0.15^{+10\%}_{-13\%}]$	$2.62^{+6\%}_{-5\%}$	$3.46^{+5\%}_{-5\%}$
c^1_{tq}	$[0.39^{+0\%}_{-1\%}]$	$-0.47^{+24\%}_{-18\%}$	$[0.50^{+3\%}_{-2\%}]$	$7.25^{+6\%}_{-5\%}$	$9.36^{+6\%}_{-5\%}$
c^1_{Qu}	$[0.33^{+0\%}_{-0\%}]$	$-0.359^{+23\%}_{-17\%}$	$[0.57^{+6\%}_{-5\%}]$	$4.68^{+6\%}_{-5\%}$	$5.96^{+6\%}_{-5\%}$
c^1_{Qd}	$[-0.11^{+0\%}_{-1\%}]$	$0.023(6)^{+114\%}_{-75\%}$	$[-0.19^{+6\%}_{-5\%}]$	$2.61^{+6\%}_{-5\%}$	$3.46^{+5\%}_{-5\%}$
$c^{1,1}_{Qq}$	$[0.57^{+0\%}_{-1\%}]$	$-0.24^{+30\%}_{-22\%}$	$[0.39^{+9\%}_{-12\%}]$	$7.25^{+6\%}_{-5\%}$	$9.34^{+5\%}_{-5\%}$
$c^{1,3}_{Qq}$	$[1.92^{+1\%}_{-1\%}]$	$0.088(7)^{+28\%}_{-20\%}$	$[1.05^{+17\%}_{-22\%}]$	$7.25^{+6\%}_{-5\%}$	$9.32^{+5\%}_{-5\%}$

Interesting interference patterns

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

Improved sensitivity

New operators opening up at NLO

4-heavy operators in top pair production

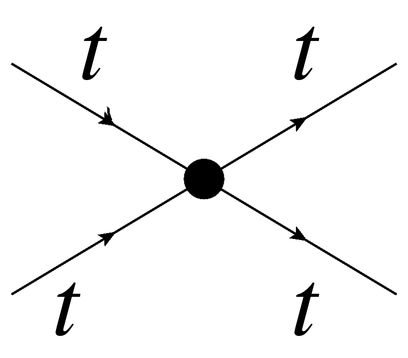
$\mathcal{O}^8_{QQ} = (\bar{Q}\gamma^\mu T^A Q)(\bar{Q}\gamma_\mu T^A Q)$

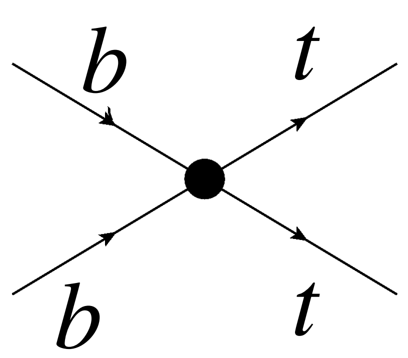
$\mathcal{O}^1_{QQ} = (\bar{Q}\gamma^\mu Q)(\bar{Q}\gamma_\mu Q)$

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

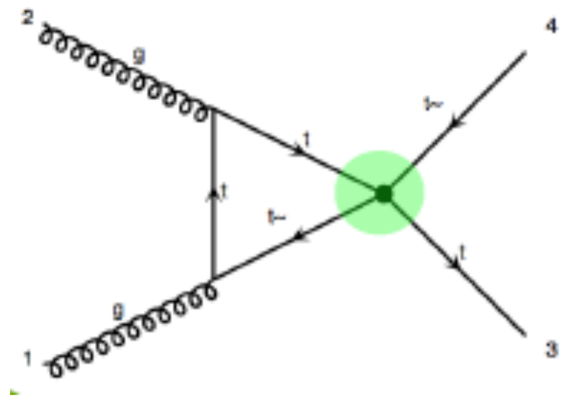
$\mathcal{O}^1_{Qt} = (\bar{Q}\gamma^\mu Q)(\bar{t}\gamma_\mu t)$

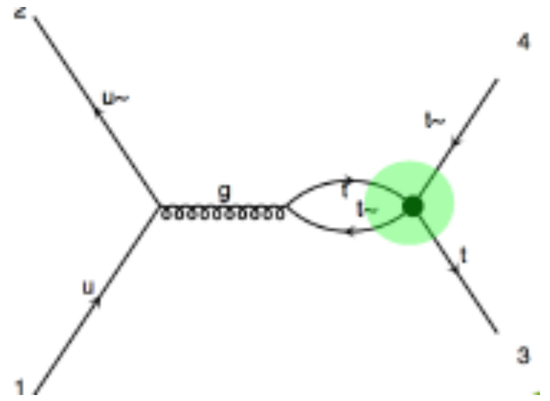
$\mathcal{O}^1_{tt} = (\bar{t}\gamma^\mu t)(\bar{t}\gamma_\mu t)$



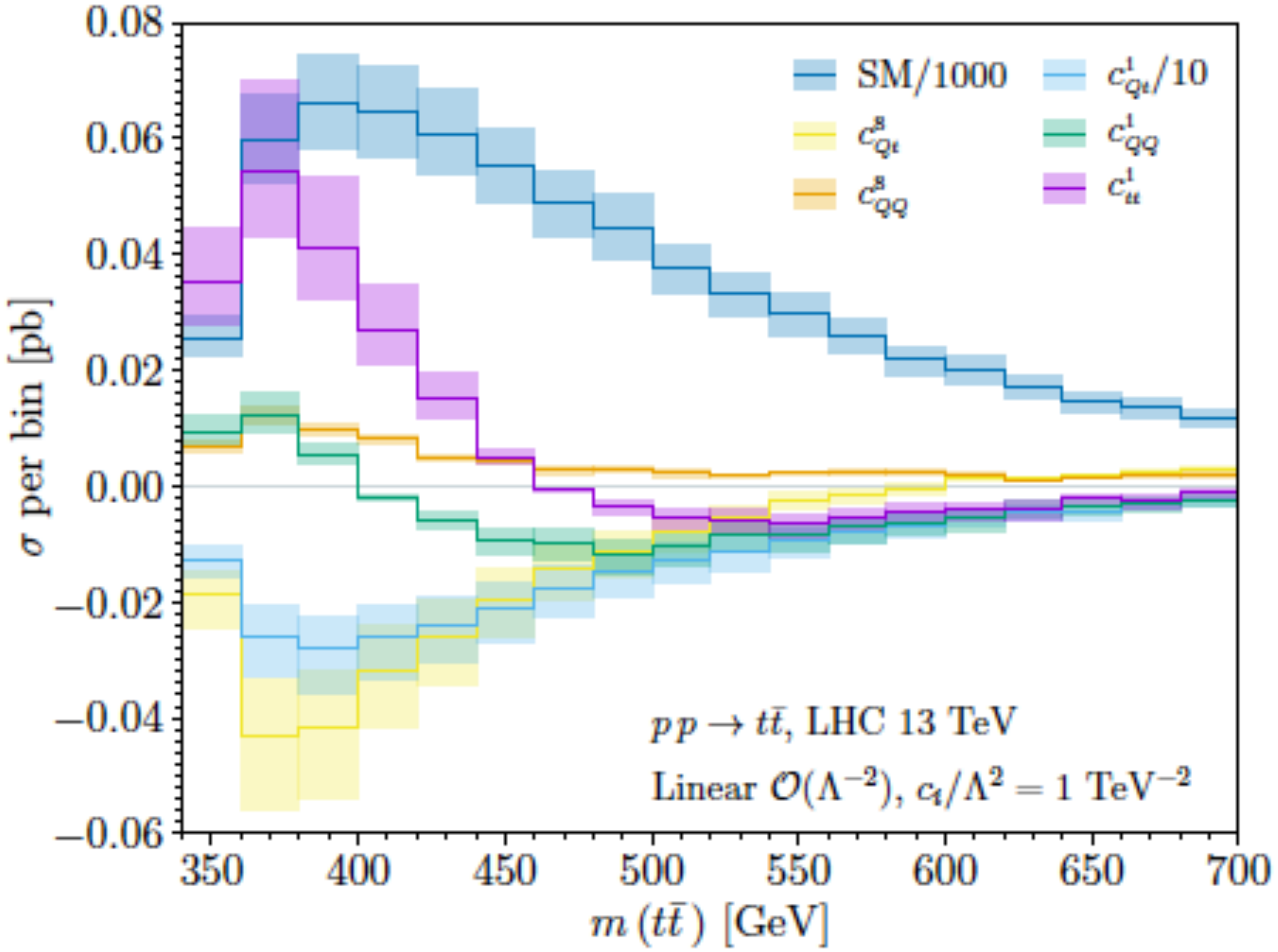


At NLO:





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}	×	$0.215^{+23\%}_{-18\%}$		×	×

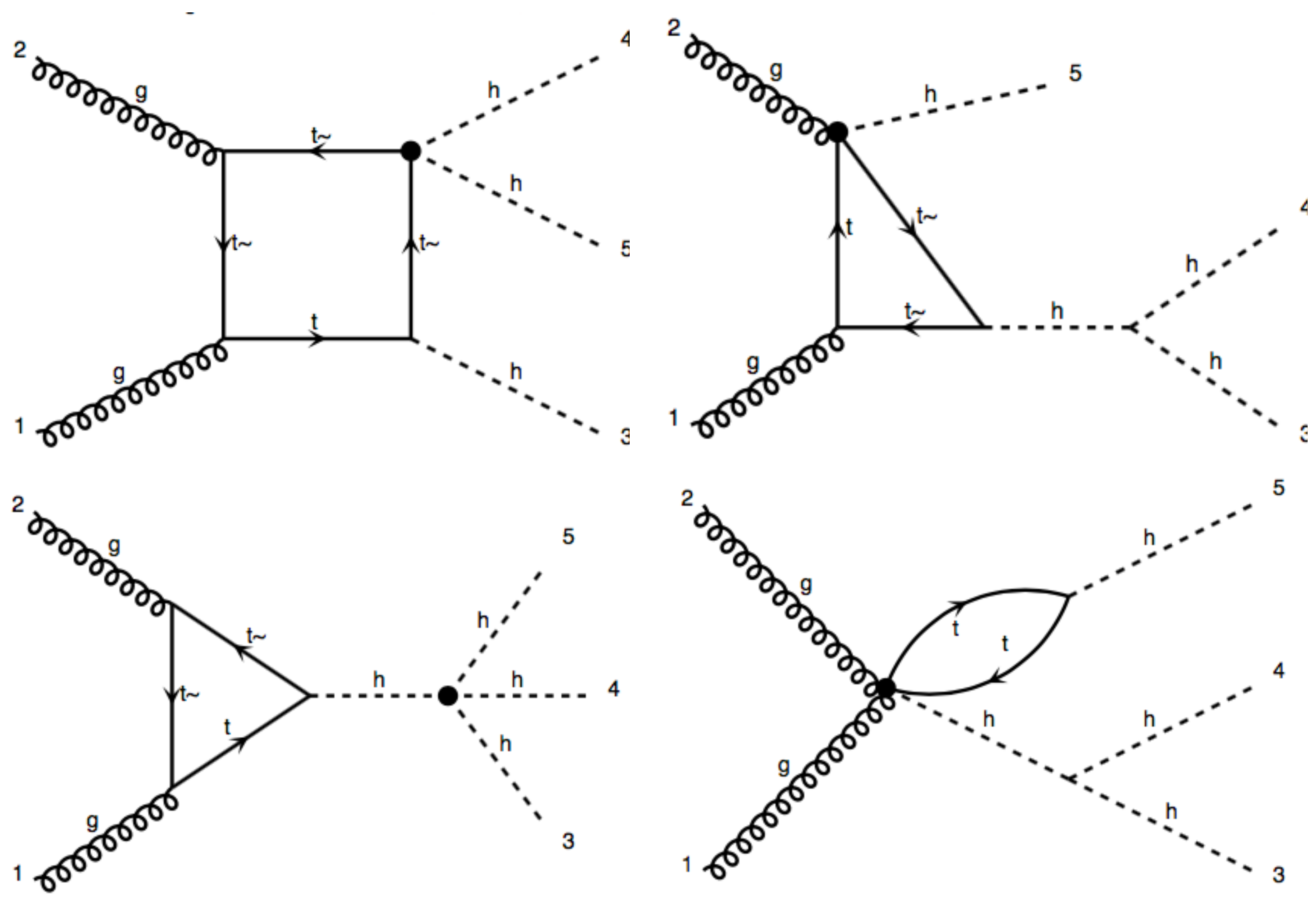


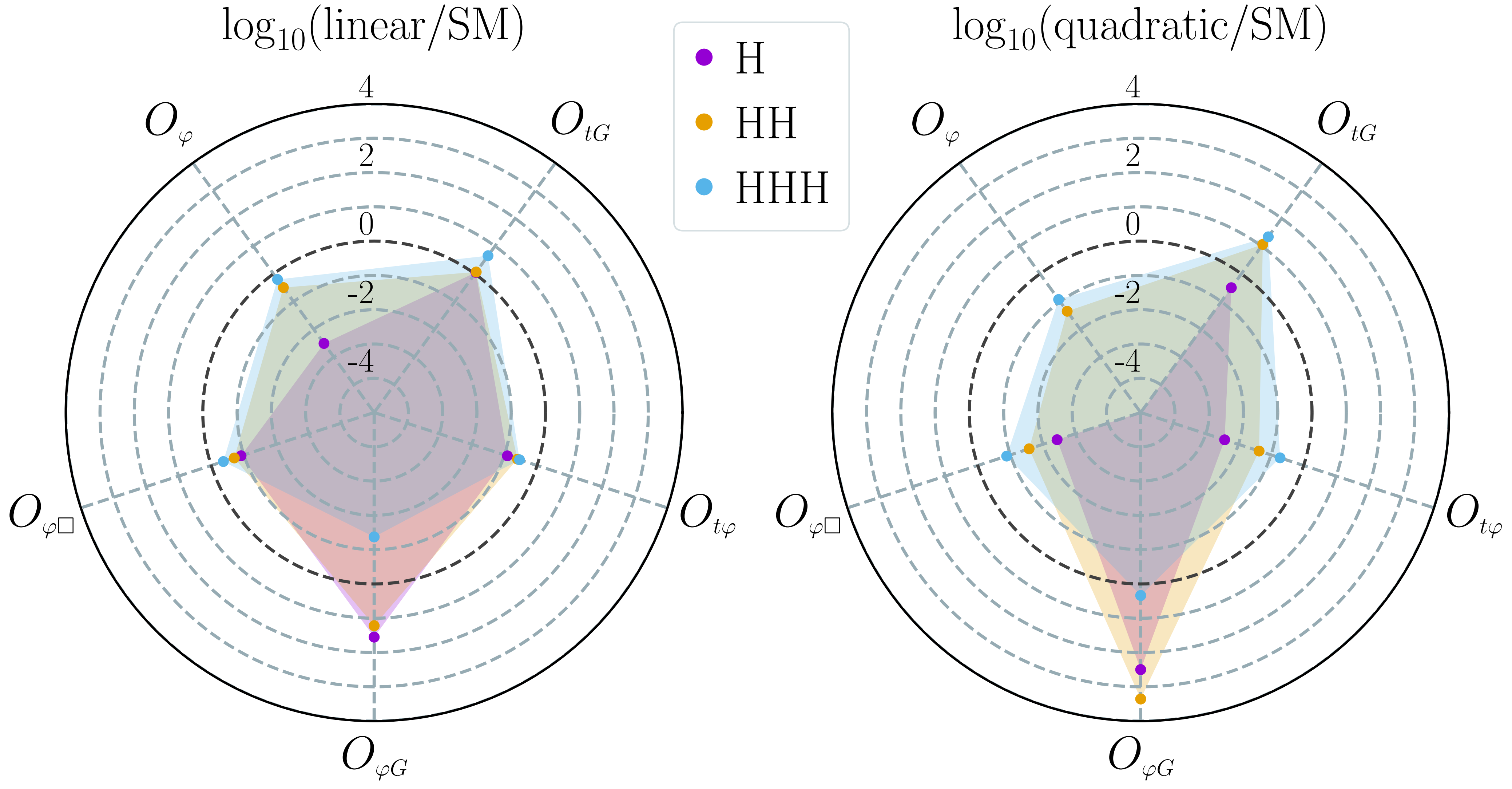
Complimentary information to ttbb and 4top production

Loop induced processes

H, HH, HHH

$$\Delta\mathcal{L}_6 = \frac{c_H}{\Lambda^2}\partial_\mu(\phi^\dagger\phi)\partial^\mu(\phi^\dagger\phi) + \frac{c_u}{\Lambda^2}\phi^\dagger\phi\,\bar{q}_L\tilde{\phi}t_R + \frac{c_6}{\Lambda^2}(\phi^\dagger\phi)^3$$
$$+ \frac{c_{tG}}{\Lambda^2}\bar{q}_L\sigma^{\mu\nu}G_{\mu\nu}\tilde{\phi}t_R + \frac{c_{\phi G}}{\Lambda^2}\phi^\dagger\phi\, G^a_{\mu\nu}G^{a\mu\nu}\ .$$

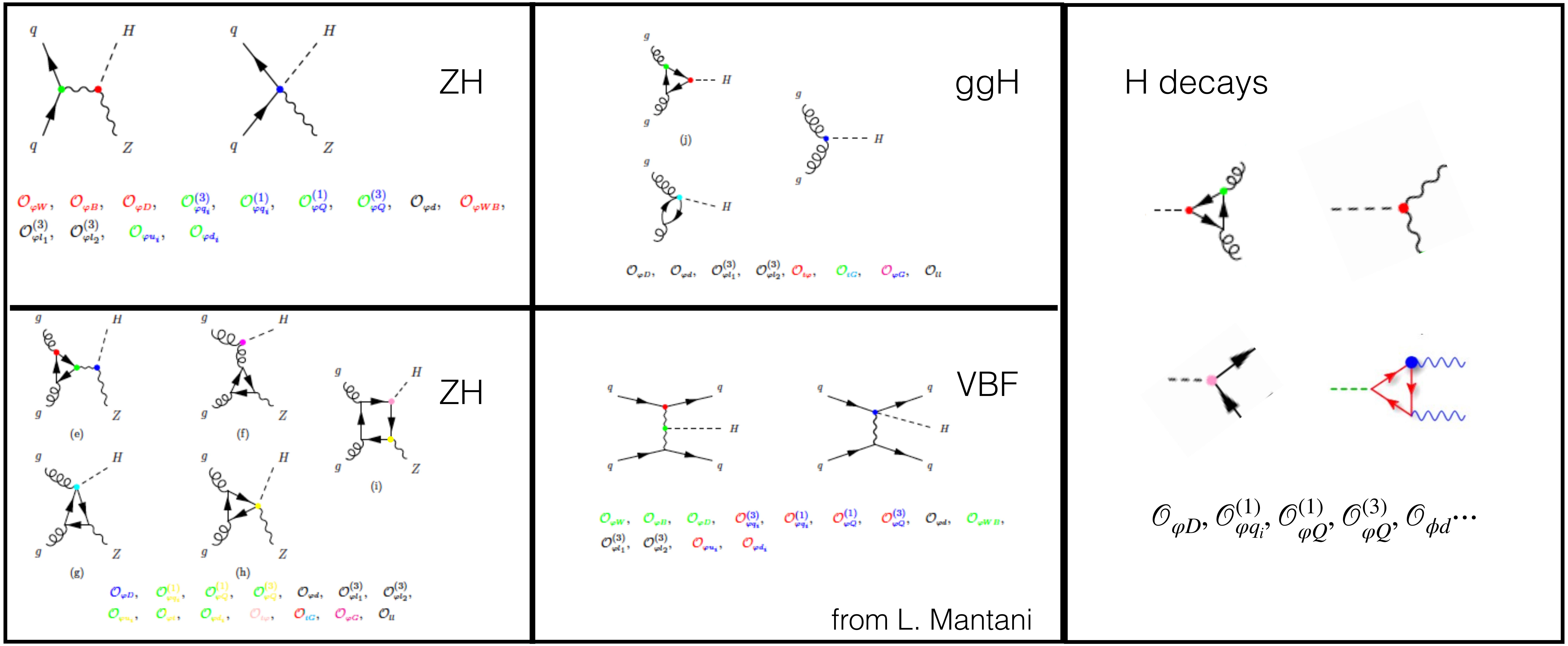




FCC-hh

Loop & tree sensitivity

Higgs production and decay



Global Higgs-top fit

PRELIMINARY

Higgs data

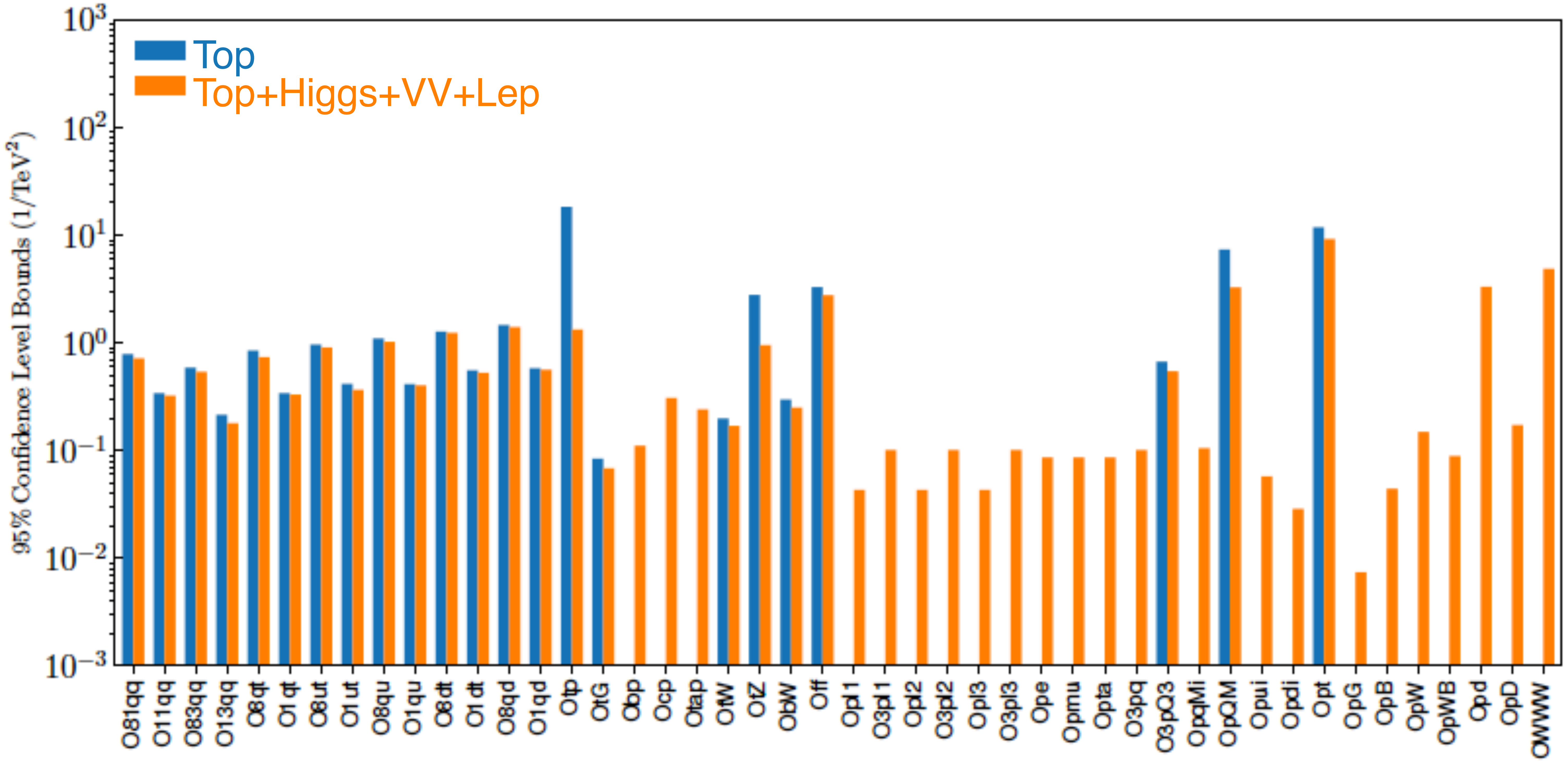
Run I & 2 signal strengths (CMS+ATLAS):
* gluon fusion
* VH
* VBF
* ttH
* H decays

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
For more details see Luca's talk yesterday

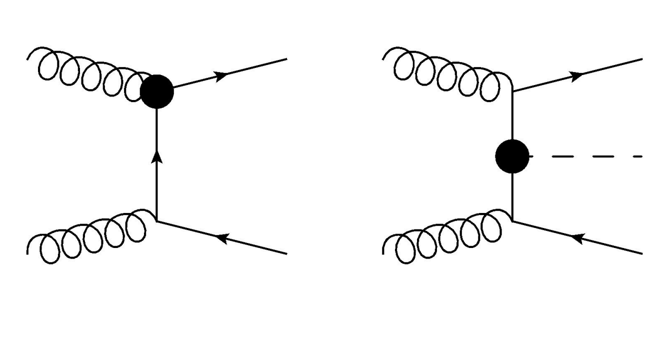
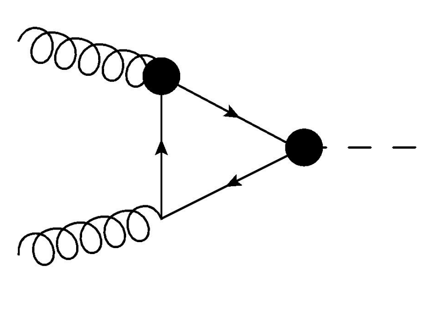
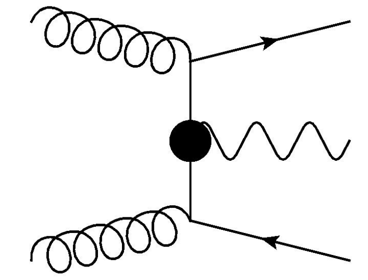
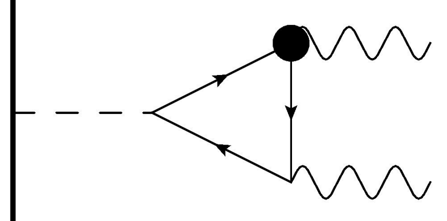
Global Higgs-top fit

Tree-loop interplay

		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

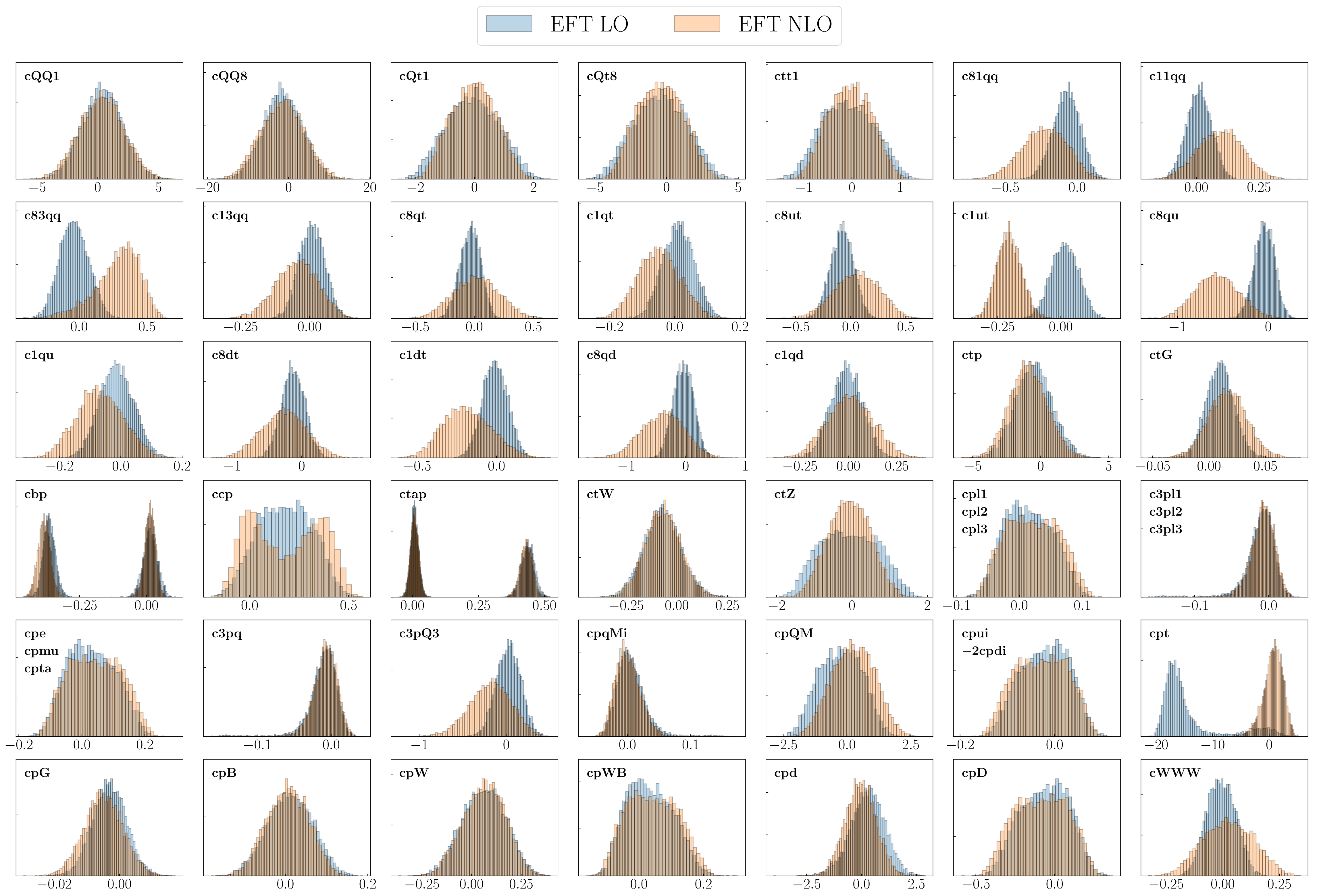
4F mostly top

	Tree	Loop
Top Yukawa Top Chromomagnetic		
ttV couplings		

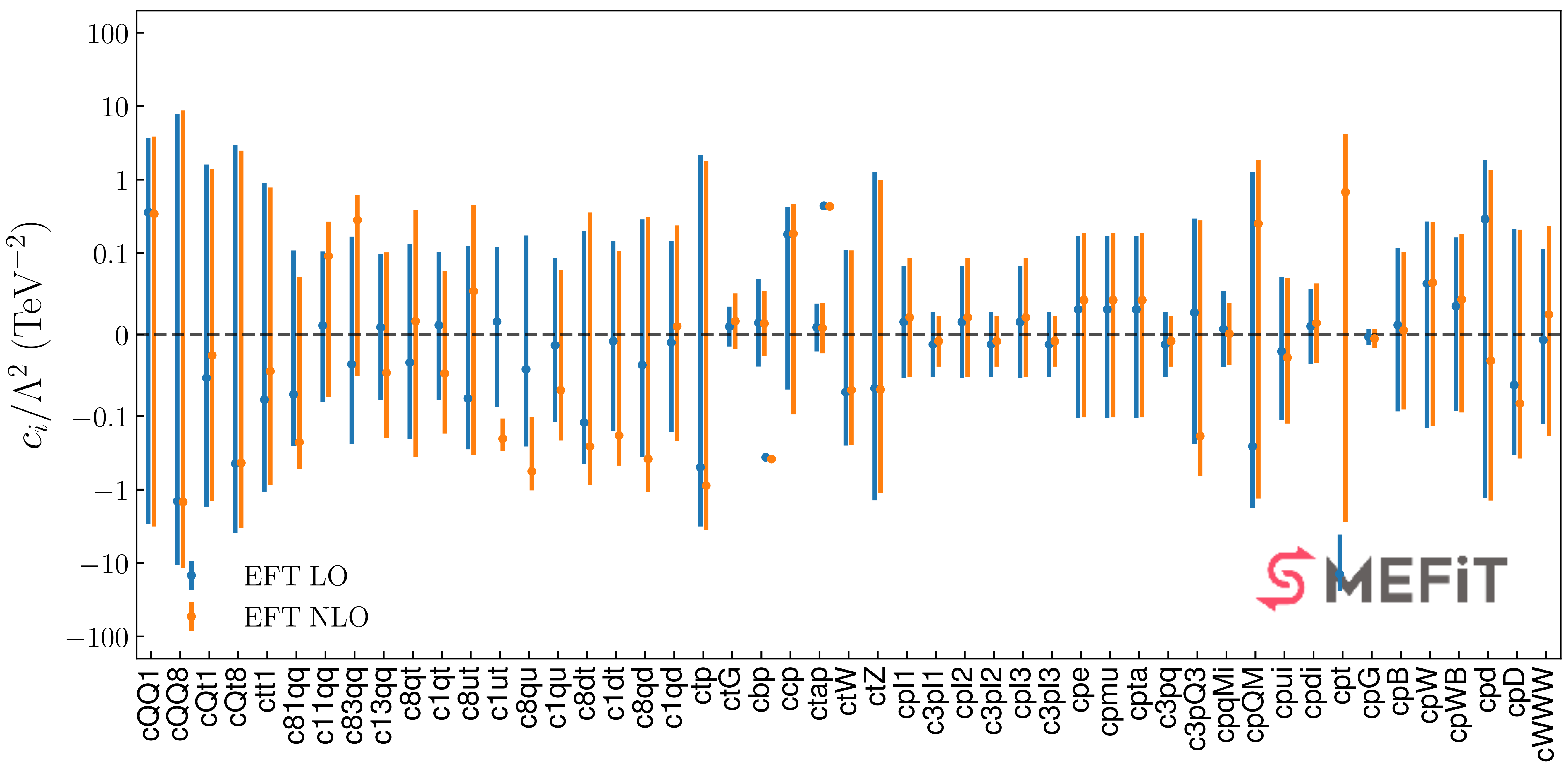
Ethier, Maltoni, Mantani, Nocera, Rojo, EV and Zhang in preparation

Impact of NLO predictions in global fits

Marginalised constraints



Posterior distributions



Significant impact of NLO for some operators

Outlook

SMEFT@NLO finally released

- Fully automated one-loop computations: NLO+PS and loop-induced
- Allows using results in global fits

Planned Extensions:

- More general flavour structure
- Light 4-f operators
- CPV