SMEFT@NLO

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Off-shell EFT/models interpretation meeting
23/9/20

Official release of SMEFT@NLO model

Automated one-loop computations in the SMEFT

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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.

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 can the code do?

Usage and validated examples:

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]
```

→ Off-shell process

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 ★

What's in the box?

Warsaw basis operators

Flavour assumption:

$$U(2)_q \times U(2)_u \times U(2)_d \times [U(1)_l \times U(1)_e]^3$$

Includes Higgs, top, gauge boson interactions

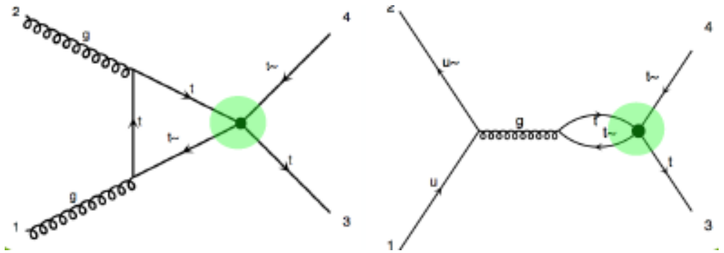
Conventions matching dim6top (LHC Top WG)

CP & Flavour conserving

And many more on the website…

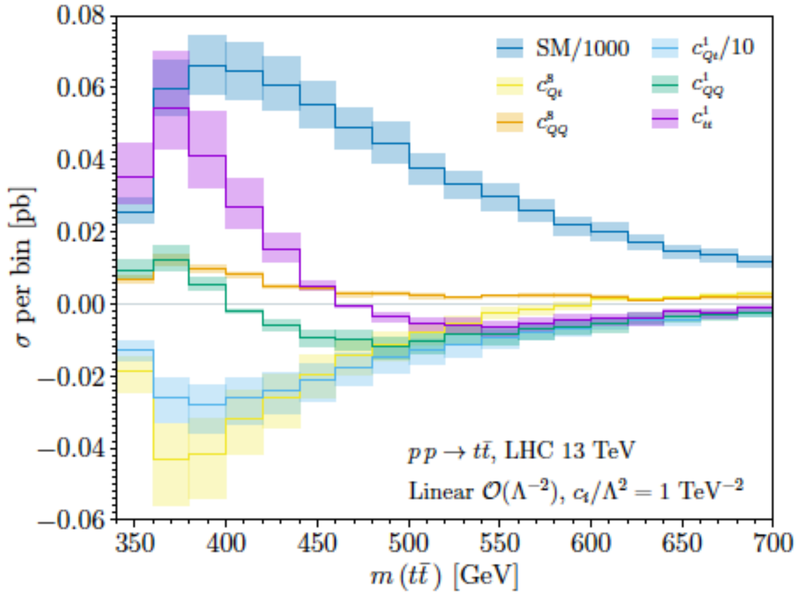
Examples

Top pair production

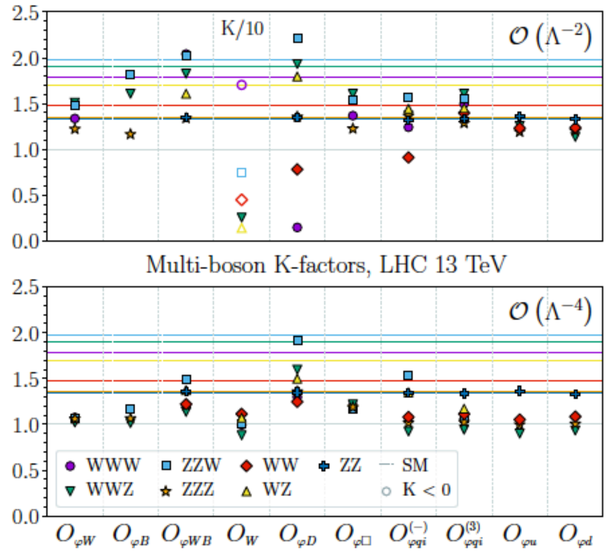


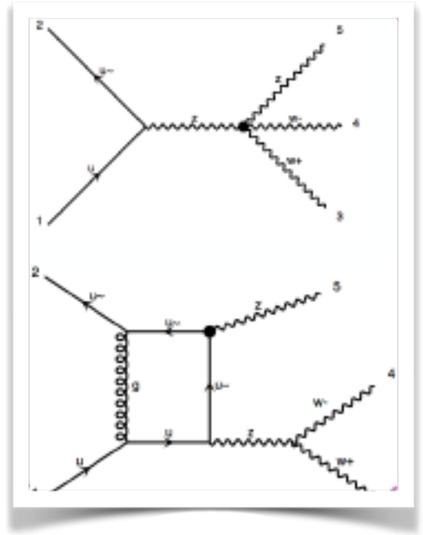
NEW

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}	×	$0.215^{+23\%}_{-18\%}$	×	×



Triboson production





First computation of VVV@NLO in the SMEFT

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

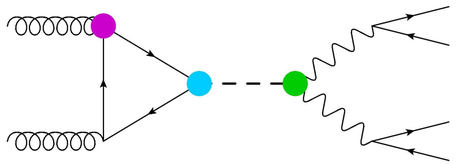
Off-shell Higgs production

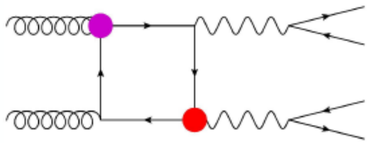
Indicative results

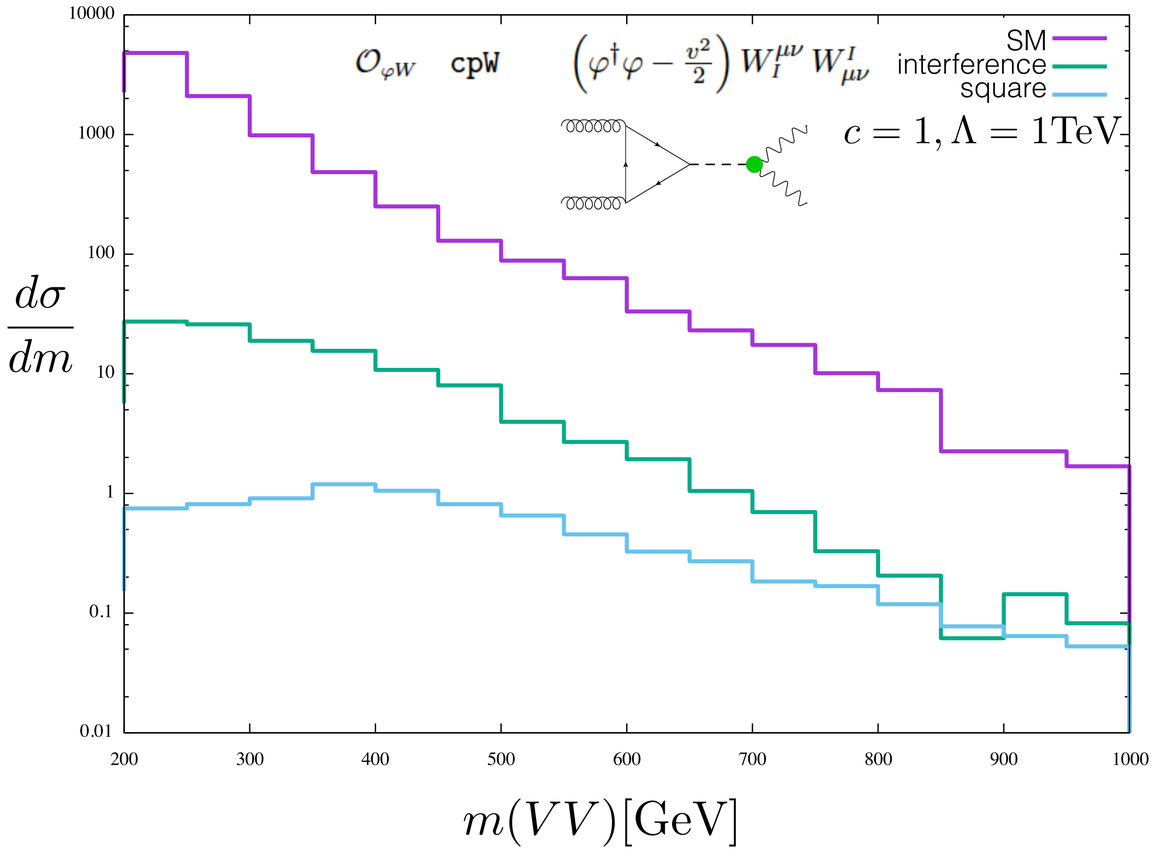
σ [fb]	$gg \to WW$	$gg \to ZZ$
σ_{SM}	4560	1485
$\sigma_{\varphi D}$	3.73	8.20
$\sigma_{\varphi D,\varphi D}$	0.188	0.040
$\sigma_{\varphi W}$	66.4	18.0
$\sigma_{\varphi W,\varphi W}$	5.69	1.42
$\sigma_{\varphi B}$		5.55
$\sigma_{\varphi B,\varphi B}$		0.132
$\sigma_{\varphi WB}$		118
$\sigma_{\varphi WB,\varphi WB}$		2.86
$\sigma_{t\varphi}$	7.51	-0.475
$\sigma_{t\varphi,t\varphi}$	0.765	0.324
$\sigma_{\varphi Q^{(3)}}$	47.7	182
$\sigma_{\varphi Q^{(3)},\varphi Q^{(3)}}$	3.21	5.68
$\sigma_{\varphi QM}$		94.0
$\sigma_{\varphi QM,\varphi QM}$		1.90
$\sigma_{\varphi t}$		-1.86
$\sigma_{\varphi t,\varphi t}$		0.476
σ_{tW}	24.1	
$\sigma_{tW,tW}$	3.32	
σ_{tZ}		-3.44
$\sigma_{tZ,tZ}$		0.195
σ_{tG}	-74.0	0.664
$\sigma_{tG,tG}$	118	45.7

Higgs

Top








```
import model SMEFTatNLO-NLO
generate g g > Z Z QCD=2 QED=2 NP=2 [QCD]
or
generate g g > e+ e- mu+ mu- /mu+ e+ QCD=2 QED=4 NP=2 [QCD]
output gg4loffshell_EFT
```