EFT tools & validation part I – SMEFT LO

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The SMEFT

fundamental assumptions:

- new physics nearly decoupled: $\Lambda \gg (v, E)$
- at the accessible scale: **SM** fields + symmetries

☛ a Taylor expansion in canonical dimensions (v/Λ or E/Λ):

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \frac{1}{\Lambda^3}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \dots$$

$\mathcal{L}_n = \sum_i C_i \mathcal{O}_i^{d=n}$

C_i free parameters (Wilson coefficients)

$\mathcal{O}_i$ invariant operators that form a complete, non redundant basis

More than a parameterization

by construction the SMEFT is always
a valid QFT and
a valid description of Nature
(assuming SM sym + fields and at $E \ll \Lambda$)

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- we can do: gauge invariant calculations, loops, RGE, etc.
  systematically improvable with higher orders in loop+EFT expansions

(Alonso),Jenkins,Manohar,Trott 1308.2627,1310.4838,1312.2014
Grojean,Jenkins,Manohar,Trott 1301.2588
Elias-Miró,Grojean,Gupta,Marzocca 1312.2928
Alonso,Chang,Jenkins,Manohar,Shotwell 1405.0486
Ghezzi,Gomez-Ambrosio,Passarino,Uccirati 1505.03706
Pruna,Signer 1408.3565
Hartmann,(Shepherd),Trott 1505.02646,1507.03568,1611.09879
Gauld,Pecjak,Scott 1512.02508
Deutschmann,Duhr,Maltoni,Vryonidou 1708.00460
Dawson et al 1801.01136,1807.11504,1808.05948,1812.00214
Dedes,Paraskevas,Rosiek,Suxho,Trifyllis 1805.00302
. . .

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- we can do: gauge invariant calculations, loops, RGE, etc.
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- we can set an ambitious & general **goal**:

  use it as a self-consistent theory and **measure** its parameters

→ a solid, systematic **probe of NP**, able to capture *any* BSM effect
→ a truly **universal language** for future data interpretation

The need for a global approach

goal: **use the SMEFT as a self-consistent theory and measure its parameters**

☛ necessary to retain **all** the operators.
generally not possible to make a selection *a priori*.
correspondence to anomalous couplings is *basis dependent*.

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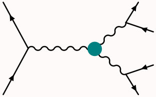
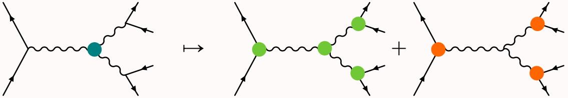
Example

BSM model → $W^a_{\mu\nu} D^\mu H^\dagger \sigma^a D^\nu H$ affecting



Going to Warsaw basis via EOM:

$$W^a_{\mu\nu} D^\mu H^\dagger \sigma^a D^\nu H \quad \mapsto \quad \mathcal{Q}_{HW},\ \mathcal{Q}_{HWB},\ \mathcal{Q}^{(3)}_{Hq},\ \mathcal{Q}^{(3)}_{Hl} + \text{Higgs ops.}$$



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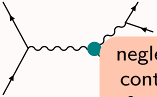

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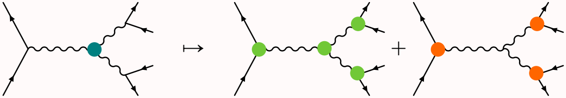

neglecting operators contributing to *Vff* formally spoils the equivalence
↓
different results in the two bases

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→ S-matrices are basis independent only if all the operators are considered

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  To make this happen one needs
  - general tools for predictions
  - control over the # of parameters

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idea: sequential strategy

- LO, resonance dominated processes
- + tails $((\bar\psi\psi)(\bar\psi\psi))$
- + NLO ⇝ see talk by **Eleni**

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  - + tails $((\bar\psi\psi)(\bar\psi\psi))$
  - + NLO ⇝ see talk by **Eleni**

  focus of this talk

The SMEFTsim package

Brivio,Jiang,Trott 1709.06492
feynrules.irmp.ucl.ac.be/wiki/SMEFT

an **UFO & FeynRules model** with*:

1. the complete B-conserving Warsaw basis for 3 generations, including all complex phases and ~~CP~~ terms
2. automatic field redefinitions to have **canonical kinetic terms**

⇝ backup

3. automatic **parameter shifts** due to the choice of an input parameters set

Main scope:

estimate **tree-level** $|\mathcal{A}_{\mathbf{SM}}\mathcal{A}^*_{\mathbf{d=6}}|$ **interference** terms → theo. accuracy $\gtrsim$ few %

* at the moment only LO, unitary gauge implementation

The SMEFTsim package

6 different implementations available

Brivio, Jiang, Trott 1709.06492

③ flavor structures: general / $U(3)^5$ symmetric / linear MFV

$\times$

② input schemes: $\hat{\alpha}_{\rm em}, \hat{m}_Z, \hat{G}_f$ / $\hat{m}_W, \hat{m}_Z, \hat{G}_f$

feynrules.irmp.ucl.ac.be/wiki/SMEFT

wiki: SMEFT

Standard Model Effective Field Theory -- The SMEFTsim package

Authors

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Pre-exported UFO files (include restriction cards)

	Set A		Set B	
	α scheme	m_W scheme	α scheme	m_W scheme
Flavor general SMEFT	SMEFTsim_A_general_alphaScheme_UFO.tar.gz	SMEFTsim_A_general_MwScheme_UFO.tar.gz	SMEFT_alpha_UFO.zip	SMEFT_mW_UFO.zip
MFV SMEFT	SMEFTsim_A_MFV_alphaScheme_UFO.tar.gz	SMEFTsim_A_MFV_MwScheme_UFO.tar.gz	SMEFT_alpha_MFV_UFO.zip	SMEFT_mW_MFV_UFO.zip
$U(3)^5$ SMEFT	SMEFTsim_A_U35_alphaScheme_UFO.tar.gz	SMEFTsim_A_U35_MwScheme_UFO.tar.gz	SMEFT_alpha_FLU_UFO.zip	SMEFT_mW_FLU_UFO.zip

SMEFTsim validation

1. Internal validation: 2 independent versions (A, B)

process	coefficient	general α	general Mw	U(3)^5 α	U(3)^5 Mw	MFV α	MFV Mw
e+ e- > w+ w-	SMlimit	2.6156 0.059793	2.6788 0.061373	2.6156 0.059793	2.6788 0.061373	2.6156 0.059793	2.6788 0.061373
e+ e- > w+ w- NP=1	Hl3	-	-	4.3384 0.10296	4.4249 0.094337	4.3384 0.10296	4.4249 0.094337
e+ e- > w+ w- NP=1	Hl311	4.6686 0.098776	4.7797 0.10282	-	-	-	-
e+ e- > w+ w- NP=1	W	4.9648 0.10804	5.06 0.11063	4.9648 0.10804	5.06 0.11063	4.9648 0.10804	5.06 0.11063
e+ e- > w+ w- NP=1	Wtil	4.9895 0.10855	5.0848 0.1111	4.9895 0.10855	5.0848 0.1111	-	-
e+ e- > z h	SMlimit	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124
e+ e- > z h NP=1	eW	-	-	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124
e+ e- > z h NP=1	eW11	1.9983 0.0050475	0.01302 0.000033124	-	-	-	-
e+ e- > z h NP=1	He	-	-	1.1756 0.0031	1.1838 0.0031194	1.1756 0.0031	1.1838 0.0031194
e+ e- > z h NP=1	He11	1.1756 0.0031	1.1838 0.0031194	-	-	-	-
e+ e- > z h NP=1	HWB	0.040274 0.00009404	0.036476 0.000084148	0.040274 0.00009404	0.036476 0.000084148	0.040274 0.00009404	0.036476 0.000084148
p p > d s~	SMlimit	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.
p p > d s~ NP=1	Delta2qd1	-	-	-	-	690 240. 9319.7	690 240. 9319.7
p p > d s~ NP=1	DeltadHq3	-	-	-	-	703 760. 9607.7	703 760. 9607.7
p p > d s~ NP=1	DeltadW	-	-	-	-	690 240. 9319.7	690 240. 9319.7
p p > d s~ NP=1	dW	-	-	690 240. 9319.7	690 240. 9319.7	-	-
p p > d s~ NP=1	dW12	692 740. 9950.4	690 240. 9319.7	-	-	-	-
p p > d s~ NP=1	Hq312	706 050. 9205.5	706 050. 9205.5	-	-	-	-
p p > d s~ NP=1	qd1	-	-	690 210. 9317.9	690 210. 9317.8	-	-
p p > d s~ NP=1	qd11221	690 260. 9318.7	690 240. 9319.7	-	-	-	-
p p > h > a a	SMlimit	0.021333 0.00017535	0.019985 0.00016427	0.021336 0.00017537	0.019986 0.00016428	0.021334 0.00017536	0.019983 0.00016426
p p > h > a a NP=1	HB	5.5024 0.045231	5.6277 0.046262	5.4973 0.045189	5.6208 0.046205	5.4967 0.045184	5.6214 0.04621
p p > h > a a NP=1	HBtil	5.8096 0.047758	5.9249 0.048704	5.8103 0.047763	5.9259 0.048712	-	-
p p > h > a a NP=1	HG	0.50651 0.0061966	0.47084 0.0057604	0.50651 0.0061966	0.47084 0.0057604	0.50651 0.0061966	0.47084 0.0057604
p p > h > a a NP=1	HGtil	0.49851 0.0061626	0.46342 0.0057291	0.49851 0.0061626	0.46342 0.0057291	-	-
p p > h > a a NP=1	HWB	-	-	-	-	2.8092 0.023091	2.9275 0.024064
p p > h > b b~	SMlimit	12.619 0.051973	12.723 0.052406	12.62 0.051978	12.724 0.052407	12.619 0.051974	12.722 0.052402
p p > h > b b~ NP=1	DeltadH	-	-	-	-	12.619 0.051974	12.723 0.052403
p p > h > b b~ NP=1	dH	-	-	12.298 0.075184	12.409 0.075862	12.988 0.079401	13.091 0.080028
p p > h > b b~ NP=1	dH33	15.557 0.064089	12.723 0.052406	-	-	-	-
p p > h > b b~ NP=1	Hbox	12.841 0.083465	12.949 0.084162	12.843 0.083474	12.949 0.084164	12.842 0.083467	12.948 0.084157
p p > h > b b~ NP=1	HG	299.8 1.2632	299.97 1.2639	299.8 1.2632	299.97 1.2639	299.8 1.2632	299.97 1.2639
p p > mu+ mu-	SMlimit	852.29 5.628	843.29 5.7365	852.29 5.628	843.29 5.7365	850.86 4.7562	842.4 4.6158
p p > mu+ mu- NP=1	ed	-	-	856.57 5.4678	848.87 5.214	856.73 4.2008	848.76 4.2018
p p > mu+ mu- NP=1	ed2211	853.99 5.6558	843.29 5.7365	-	-	-	-
p p > mu+ mu- NP=1	eH	-	-	852.29 5.628	843.29 5.7365	850.86 4.7562	842.4 4.6158
p p > mu+ mu- NP=1	eW	-	-	852.29 5.628	843.29 5.7365	850.86 4.7562	842.4 4.6158
p p > mu+ mu- NP=1	eW22	861.01 5.5611	843.29 5.7365	-	-	-	-
p p > mu+ mu- NP=1	ledq	-	-	854.23 5.4471	846.83 5.164	854.71 4.1909	846.98 4.1817
p p > mu+ mu- NP=1	lq12211	851.56 5.7575	843.47 5.9407	-	-	-	-
p p > mu+ mu- NP=1	lu	-	-	849.68 5.6077	841.96 5.7488	848.25 4.7321	841.07 4.631
p p > mu+ mu- NP=1	lu2211	851.05 5.622	843.29 5.7365	-	-	-	-
p p > u u~	SMlimit	4.479×10^{6} 36 717.	4.479×10^{6} 36 717.	4.479×10^{6} 36 717.	4.479×10^{6} 36 717.	4.479×10^{6} 36 717.	4.479×10^{6} 36 717.
p p > u u~ NP=1	Delta1uqq1	-	-	-	-	4.4174×10^{6} 42 604.	4.4167×10^{6} 42 647.
p p > u u~ NP=1	Delta2uu	-	-	-	-	4.4174×10^{6} 42 604.	4.4167×10^{6} 42 647.
p p > u u~ NP=1	qq1	-	-	4.4205×10^{6} 42 250.	4.4208×10^{6} 42 265.	4.4203×10^{6} 42 248.	4.4205×10^{6} 42 262.
p p > u u~ NP=1	qq11212	4.4176×10^{6} 42 604.	4.4169×10^{6} 42 648.	-	-	-	-
p p > u u~ NP=1	qu1	-	-	4.4186×10^{6} 42 434.	4.4178×10^{6} 42 512.	-	-
p p > u u~ NP=1	qu8	-	-	-	-	4.3896×10^{6} 51 992.	4.3896×10^{6} 51 992.
p p > u u~ NP=1	qu81111	4.4207×10^{6} 42 124.	4.4169×10^{6} 42 648.	-	-	-	-
p p > u u~ NP=1	quqd1	-	-	4.4177×10^{6} 42 607.	4.417×10^{6} 42 651.	4.4174×10^{6} 42 604.	4.4167×10^{6} 42 647.
p p > u u~ NP=1	quqd11111	4.4176×10^{6} 42 604.	4.4169×10^{6} 42 648.	-	-	-	-
p p > u u~ NP=1	uB	-	-	4.4176×10^{6} 42 604.	4.4169×10^{6} 42 648.	4.4174×10^{6} 42 604.	4.4168×10^{6} 42 647.
p p > u u~ NP=1	uB11	4.4166×10^{6} 42 664.	4.4169×10^{6} 42 648.	-	-	-	-
p p > u u~ NP=1	uG	-	-	4.4272×10^{6} 45 585.	4.4265×10^{6} 45 625.	4.4174×10^{6} 42 604.	4.4167×10^{6} 42 647.
p p > u u~ NP=1	uG11	4.4276×10^{6} 45 716.	4.4169×10^{6} 42 648.	-	-	-	-
p p > u u~ NP=1	uH	-	-	4.4176×10^{6} 42 604.	4.4169×10^{6} 42 648.	4.4174×10^{6} 42 604.	4.4168×10^{6} 42 647.
p p > u u~ NP=1	uH11	4.4177×10^{6} 42 613.	4.4169×10^{6} 42 648.	-	-	-	-
p p > u u~ NP=1	uu	-	-	4.4165×10^{6} 42 597.	4.4205×10^{6} 42 239.	4.4205×10^{6} 41 911.	4.4209×10^{6} 41 917.
p p > u u~ NP=1	uu1122	4.4176×10^{6} 42 604.	4.4169×10^{6} 42 648.	-	-	-	-
p p > u u~ NP=1	uW	-	-	4.4176×10^{6} 42 604.	4.4169×10^{6} 42 648.	4.4174×10^{6} 42 604.	4.4168×10^{6} 42 647.
p p > u u~ NP=1	uW11	4.3896×10^{6} 51 992.	4.3896×10^{6} 51 992.	-	-	-	-
p p > w+ h	SMlimit	0.63923 0.0032239	0.65676 0.0033139	0.63923 0.0032239	0.65676 0.0033139	0.63923 0.0032239	0.65676 0.0033139
p p > w+ h NP=1	DeltauHq3	-	-	-	-	0.63923 0.0032239	0.65676 0.0033139
p p > w+ h NP=1	Hbox	0.71908 0.0036267	0.7388 0.0037278	0.71908 0.0036267	0.7388 0.0037278	0.71908 0.0036267	0.7388 0.0037278
p p > w+ h NP=1	HD	0.56586 0.00285	0.637 0.0032142	0.56586 0.00285	0.637 0.0032142	0.56744 0.0028579	0.637 0.0032142
p p > w+ h NP=1	Hq3	-	-	3.7622 0.03539	3.8038 0.035528	0.63923 0.0032239	0.65676 0.0033139
p p > w+ h NP=1	Hq311	3.6101 0.035372	3.6503 0.03551	-	-	-	-
p p > w+ h NP=1	HW	1.4421 0.0065889	1.4762 0.0067496	1.4421 0.0065889	1.4762 0.0067496	1.4421 0.0065889	1.4762 0.0067496
p p > w+ h NP=1	HWB	0.5185 0.0026076	0.65676 0.0033139	0.5185 0.0026076	0.65676 0.0033139	0.52414 0.0026359	0.65676 0.0033139
p p > w+ h NP=1	HWtil	0.79358 0.0036227	0.81285 0.0037123	0.79358 0.0036227	0.81285 0.0037123	-	-
p p > w+ h NP=1	ll	-	-	0.69534 0.0035085	0.69718 0.0035178	0.69534 0.0035085	0.69718 0.0035178
p p > w+ h NP=1	ll1221	0.75297 0.0038009	0.7388 0.0037278	-	-	-	-
p p > z > e+ e-	SMlimit	631.87 3.3394	637.92 3.3798	631.87 3.3394	637.92 3.3798	627.91 3.3526	636.64 3.4105
p p > z > e+ e- NP=1	HD	607.81 3.2005	645.36 3.4837	607.81 3.2005	645.36 3.4837	602.35 3.2094	643.87 3.4666
p p > z > e+ e- NP=1	He	-	-	570.36 3.0406	580.92 3.0976	568.3 3.0678	580.03 3.1069
p p > z > e+ e- NP=1	He11	566.15 3.0181	576.89 3.0763	-	-	-	-
p p > z > e+ e- NP=1	Hl3	-	-	593.6 3.1007	622.95 3.3241	588.37 3.1174	619.59 3.3496
p p > z > e+ e- NP=1	Hl311	655.41 3.4736	680.76 3.6298	-	-	-	-
p p > z > e+ e- NP=1	HWB	624.66 3.3011	666.73 3.6543	624.66 3.3011	666.73 3.6543	618.47 3.2863	665.22 3.5879

SMEFTsim validation

1. Internal validation: 2 independent versions (A, B)

σ(SM+int+quadratic) for $C_i = 1$, $\Lambda = 1$ TeV

process	coefficient	general α	general Mw	U(3)^5 α	U(3)^5 Mw	MFV α	MFV Mw
e+ e- > w+ w-	SMlimit	2.6156 0.059793	2.6788 0.061373	2.6156 0.059793	2.6788 0.061373	2.6156 0.059793	2.6788 0.061373
e+ e- > w+ w- NP=1	Hl3	-	-	4.3384 0.10296	4.4249 0.094337	4.3384 0.10296	4.4249 0.094337
e+ e- > w+ w- NP=1	Hl311	4.6686 0.098776	4.7797 0.10282	-	-	-	-
e+ e- > w+ w- NP=1	W	4.9648 0.10804	5.06 0.11063	4.9648 0.10804	5.06 0.11063	4.9648 0.10804	5.06 0.11063
e+ e- > w+ w- NP=1	Wtil	4.9895 0.10855	5.0848 0.1111	4.9895 0.10855	5.0848 0.1111	-	-
e+ e- > z h	SMlimit	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124
e+ e- > z h NP=1	eW	-	-	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124
e+ e- > z h NP=1	eW11	1.9983 0.0050475	0.01302 0.000033124	-	-	-	-
e+ e- > z h NP=1	He	-	-	1.1756 0.0031	1.1838 0.0031194	1.1756 0.0031	1.1838 0.0031194
e+ e- > z h NP=1	He11	1.1756 0.0031	1.1838 0.0031194	-	-	-	-
e+ e- > z h NP=1	HWB	0.040274 0.00009404	0.036476 0.000084148	0.040274 0.00009404	0.036476 0.000084148	0.040274 0.00009404	0.036476 0.000084148
p p > d s~	SMlimit	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.
p p > d s~ NP=1	Delta2qd1	-	-	-	-	690 240. 9319.7	690 240. 9319.7
p p > d s~ NP=1	DeltadHq3	-	-	-	-	703 760. 9607.7	703 760. 9607.7
p p > d s~ NP=1	DeltadW	-	-	-	-	690 240. 9319.7	690 240. 9319.7
p p > d s~ NP=1	dW	-	-	690 240. 9319.7	690 240. 9319.7	-	-
p p > d s~ NP=1	dW12	692 740. 9950.4	690 240. 9319.7	-	-	-	-
p p > d s~ NP=1	Hq312	706 050. 9205.5	706 050. 9205.5				

xsec [pb]
err

MG5 results with set A

SMEFTsim validation

1. Internal validation: 2 independent versions (A, B)

σ(SM+int+quadratic) for $C_i = 1$, $\Lambda = 1$ TeV

process	coefficient	general α	general Mw	U(3)^5 α	U(3)^5 Mw	MFV α	MFV Mw
e+ e- > w+ w-	SMlimit	2.6156 0.059793	2.6788 0.061373	2.6156 0.059793	2.6788 0.061373	2.6156 0.059793	2.6788 0.061373
e+ e- > w+ w- NP=1	Hl3	-	-	4.3384 0.10296	4.4249 0.094337	4.3384 0.10296	4.4249 0.094337
e+ e- > w+ w- NP=1	Hl311	4.6686 0.098776	4.7797 0.10282	-	-	-	-
e+ e- > w+ w- NP=1	W	4.9648 0.10804	5.06 0.11063	4.9648 0.10804	5.06 0.11063	4.9648 0.10804	5.06 0.11063
e+ e- > w+ w- NP=1	Wtil	4.9895 0.10855	5.0848 0.1111	4.9895 0.10855	5.0848 0.1111	-	-
e+ e- > z h	SMlimit	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124
e+ e- > z h NP=1	eW	-	-	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124
e+ e- > z h NP=1	eW11	1.9983 0.0050475	0.01302 0.000033124	-	-	-	-
e+ e- > z h NP=1	He	-	-	1.1756 0.0031	1.1838 0.0031194	1.1756 0.0031	1.1838 0.0031194
e+ e- > z h NP=1	He11	1.1756 0.0031	1.1838 0.0031194	-	-	-	-
e+ e- > z h NP=1	HWB	0.040274 0.00009404	0.036476 0.000084148	0.040274 0.00009404	0.036476 0.000084148	0.040274 0.00009404	0.036476 0.000084148
p p > d s~	SMlimit	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.
p p > d s~ NP=1	Delta2qd1	-	-	-	-	690 240. 9319.7	690 240. 9319.7
p p > d s~ NP=1	DeltadHq3	-	-	-	-	703 760. 9607.7	703 760. 9607.7
p p > d s~ NP=1	DeltadW	-	-	-	-	690 240. 9319.7	690 240. 9319.7
p p > d s~ NP=1	dW	-	-	690 240. 9319.7	690 240. 9319.7	-	-
[illegible]	[illegible]W12	692 740. 9950.4	690 240. 9319.7	-	-	-	-
[illegible]	[illegible]312	706 050. 9205.5	706 050. 9205.5				

5–10 coeff. $\times$ $\sim$ 20 processes

xsec [pb]
err

MG5 results with set A

SMEFTsim validation

1. Internal validation: 2 independent versions

3 flavor assum. × 2 schemes

σ(SM+int+quadratic) for $C_i = 1$, $\Lambda = 1$ TeV

process	coefficient	general α	general Mw	U(3)^5 α	U(3)^5 Mw	MFV α	MFV Mw
e+ e- > w+ w-	SMlimit	2.6156 0.059793	2.6788 0.061373	2.6156 0.059793	2.6788 0.061373	2.6156 0.059793	2.6788 0.061373
e+ e- > w+ w- NP=1	Hl3	–	–	4.3384 0.10296	4.4249 0.094337	4.3384 0.10296	4.4249 0.094337
e+ e- > w+ w- NP=1	Hl311	4.6686 0.098776	4.7797 0.10282	–	–	–	–
e+ e- > w+ w- NP=1	W	4.9648 0.10804	5.06 0.11063	4.9648 0.10804	5.06 0.11063	4.9648 0.10804	5.06 0.11063
e+ e- > w+ w- NP=1	Wtil	4.9895 0.10855	5.0848 0.1111	4.9895 0.10855	5.0848 0.1111	–	–
e+ e- > z h	SMlimit	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124
e+ e- > z h NP=1	eW	–	–	0.013009 0.000032914	0.01302 0.000033124	0.013009 0.000032914	0.01302 0.000033124
e+ e- > z h NP=1	eW11	1.9983 0.0050475	0.01302 0.000033124	–	–	–	–
e+ e- > z h NP=1	He	–	–	1.1756 0.0031	1.1838 0.0031194	1.1756 0.0031	1.1838 0.0031194
e+ e- > z h NP=1	He11	1.1756 0.0031	1.1838 0.0031194	–	–	–	–
e+ e- > z h NP=1	HWB	0.040274 0.00009404	0.036476 0.000084148	0.040274 0.00009404	0.036476 0.000084148	0.040274 0.00009404	0.036476 0.000084148
p p > d s~	SMlimit	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.	688 390. 11 858.
p p > d s~ NP=1	Delta2qd1	–	–	–	–	690 240. 9319.7	690 240. 9319.7
p p > d s~ NP=1	DeltadHq3	–	–	–	–	703 760. 9607.7	703 760. 9607.7
p p > d s~ NP=1	DeltadW	–	–	–	–	690 240. 9319.7	690 240. 9319.7
p p > d s~ NP=1	dW	–	–	690 240. 9319.7	690 240. 9319.7	–	–
[illegible]	[illegible]W12	692 740. 9950.4	690 240. 9319.7	–	–	–	–
[illegible]	[illegible]12	706 050. 9205.5	706 050. 9205.5	[illegible]	[illegible]	[illegible]	[illegible]

5–10 coeff. ×
∼ 20 processes

xsec [pb]
err

MG5 results with set A

SMEFTsim validation

1. Internal validation: 2 independent versions (A, B)

2. Validation against `dim6top`

feynrules.irmp.ucl.ac.be/wiki/dim6top – G.Durieux,C.Zhang

Top WG note: Aguilar-Saavedra et al. 1802.07237

$\sigma(\text{int.})/\sigma(\text{SM})$ for $C_i = 1$, $\Lambda = 1$ TeV [permille]

		$pp \to t\bar{t}$	$pp \to t\bar{t}\,b\bar{b}$	$pp \to t\bar{t}\,t\bar{t}$	$pp \to t\bar{t}\,e^+\nu$	$pp \to t\bar{t}\,e^+e^-$	$pp \to t\bar{t}\,\gamma$	$pp \to t\bar{t}\,h$	$pp \to tj$	$pp \to t\,e^-\bar{\nu}$	$pp \to tj\,e^+e^-$	$pp \to tj\,\gamma$	$pp \to tj\,h$
SM	sm	5.2×10^2 pb	1.9 pb	0.0098 pb	0.02 pb	0.016 pb	1.4 pb	0.4 pb	55 pb	2.5 pb	0.0054 pb	0.39 pb	0.016 pb
c_{QQ}^1	cQQ1	−0.25	−1.9	-1×10^2		−1.6	−0.67	−0.71					
c_{QQ}^8	cQQ8	−0.16	−3.2	−34		−0.91	−0.5	−0.27					
c_{Qt}^1	cQt1	−0.15	−5.6	1×10^2		−0.76	−0.19	−0.55					
c_{Qt}^8	cQt8	−0.053	−1.8	−41		−0.18	−0.095	−0.15					
c_{Qb}^1	cQb1	−0.0055	0.72	−0.052		−0.015	−0.007	−0.026					
c_{Qb}^8	cQb8	0.14	3.9	0.12		0.35	0.16	0.56					
c_{tt}^1	ctt1			-1.8×10^2									
c_{tb}^1	ctb1	−0.0095	0.46	−0.059		−0.02	−0.026	−0.039					
c_{tb}^8	ctb8	0.13	3.5	0.11		0.26	0.31	0.56					
c_{QtQb}^1	cQtQb1												
c_{QtQb}^8	cQtQb8												
c_{QtQb}^{1I}	cQtQb1I												
c_{QtQb}^{8I}	cQtQb8I												
$c_{Qq}^{3,8}$	cQq83	2.7	−0.11	4.7	−85	−20	8.5	15	-3.4×10^{-15}		-6.4×10^{-15}	-5.2×10^{-15}	-4.1×10^{-15}
$c_{Qq}^{1,8}$	cQq81	12	7.1	25	2.6×10^2	71	40	75					
c_{tq}^8	ctq8	13	8.2	27	2.6×10^2	62	51	74					
c_{Qu}^8	cQu8	7.4	4.4	18		21	41	44					
c_{tu}^8	ctu8	7.4	3	16		14	22	45					
c_{Qd}^8	cQd8	5	3	11		17	7.3	29					
c_{td}^8	ctd8	5	2.1	10		12	10	28					
$c_{Qq}^{3,1}$	cQq13	3.3	3	5.8	1.1×10^2	22	11	18	-3.8×10^2		-7.9×10^2	-6.1×10^2	-4.6×10^2
$c_{Qq}^{1,1}$	cQq11	0.94	−1.4	−7.7	−5.9	−5	3	5.4					
c_{tq}^1	ctq1	0.65	2.4	−7.9	8.7	0.84	3.7	4.8					
c_{Qu}^1	cQu1	0.57	1.5	−5.2		1.5	2.9	4.3					
c_{tu}^1	ctu1	1.1	−0.29	−3.8		2.3	3.3	6.6					
c_{Qd}^1	cQd1	−0.19	0.55	−4		−0.66	−0.3	−1.4					
c_{td}^1	ctd1	−0.37	−1.3	−5		−0.91	−1.3	−2.1					
$c_{t\varphi}$	ctp		−0.00035	−9.1	−0.034	−0.0093		-1.2×10^2					−68
$c_{\varphi Q}^-$	cpQM	−0.063	1	−41	−0.76	-1×10^2	−0.13	−0.29			21		
$c_{\varphi Q}^3$	cpQ3	0.68	22	0.065	0.46	3.7	1.5	1.8	1.2×10^2	1.2×10^2	2.2×10^2	1.2×10^2	1.3×10^2
$c_{\varphi t}$	cpt	−0.024	2.8	42	−0.36	68	−0.058	−0.16			5.2		
$c_{\varphi tb}$	cptb												
c_{tW}	ctW	0.98	1	−34	13	1.1	69	9.4	84	−76	45	50	9.1×10^2
c_{tZ}	ctZ	−0.54	0.028	27	−0.048	−3.6	−55	−4.3			−10	−6	
c_{bW}	cbW												
c_{tG}	ctG	2.7×10^2	2.5×10^2	3.8×10^2	2.4×10^2	3.1×10^2	2.4×10^2	8.4×10^2		59			
$c_{t\varphi}^I$	ctpI		-7.3×10^{-7}	0.045	−0.00064	−0.00029		0.045					−0.21
$c_{\varphi tb}^I$	cptbI												
c_{tW}^I	ctWI	4.8×10^{-6}	0.032	−1.6	−0.19	0.29	0.91	0.031	1.6×10^{-16}	−1.4	0.47	0.022	−0.13
c_{tZ}^I	ctZI	-1.4×10^{-6}	0.1	−1.2	0.0098	3.2	−0.56	−0.057			−0.87	0.67	
c_{bW}^I	cbWI												
c_{tG}^I	ctGI	−0.00098	0.48	0.66	0.031	−0.7	0.019	−2.4		0.4			
$c_{Ql}^{3(1)}$	cQl31				0.011	0.06				4.1	6		
$c_{Ql}^{-(1)}$	cQlM1				−0.0062	−9.8					2.2		
$c_{Qe}^{(1)}$	cQe1					−1.5					−0.39		
$c_{tl}^{(1)}$	ctl1				−0.0023	−3.6					−0.036		
$c_{te}^{(1)}$	cte1					−6.7					0.064		

SMEFTsim validation

1. Internal validation: 2 independent versions (A, B)

2. Validation against `dim6top`

feynrules.irmp.ucl.ac.be/wiki/dim6top – G.Durieux,C.Zhang

Top WG note: Aguilar-Saavedra et al. 1802.07237

$\sigma(\text{int.})/\sigma(\text{SM})$ for $C_i = 1$, $\Lambda = 1$ TeV [permille]

		$pp \to t\bar t$	$pp \to t\bar t\, b\bar b$	$pp \to t\bar t\, t\bar t$	$pp \to t\bar t\, e^+\nu$	$pp \to t\bar t\, e^+e^-$	$pp \to t\bar t\gamma$	$pp \to t\bar t\, h$	$pp \to tj$	$pp \to t\, e^-\bar\nu$	$pp \to tj\, e^+e^-$	$pp \to tj\gamma$	$pp \to tj\, h$
SM	sm	5.2×10^2 pb	1.9 pb	0.0098 pb	0.02 pb	0.016 pb	1.4 pb	0.4 pb	55 pb	2.5 pb	0.0054 pb	0.39 pb	0.016 pb
c^1_{QQ}	cQQ1	−0.25	−1.9	-1×10^2		−1.6	−0.67	−0.71					
c^8_{QQ}	cQQ8	−0.16	−3.2	−34		[illegible].91	−0.5	−0.27					
c^1_{Qt}	cQt1	−0.15	−5.6	1×10^2		−0.[illegible]	−0.19	−0.55					
c^8_{Qt}	cQt8	−0.053	−1.8	−41		−0.18	−0.095	−0.15					
c^1_{Qb}	cQb1	−0.0055	0.72	−0.052		−0.015	−0.007	−0.026					
c^8_{Qb}	cQb8	0.14	3.9	0.12		0.35	[illegible]16	0.56					
c^1_{tt}	ctt1			-1.8×10^2									
c^1_{tb}	ctb1	−0.0095	0.46	−0.059		−0.02	−0.02[illegible]	−0.039					
c^8_{tb}	ctb8	0.13	3.5	0.11		0.26	0.31	0.56					
c^1_{QtQb}	cQtQb1												
c^8_{QtQb}	cQtQb8												
c^{1I}_{QtQb}	cQtQb1I												
c^{8I}_{QtQb}	cQtQb8I												
$c^{3,8}_{Qq}$	cQq83	2.7	−0.11	4.7	−85	−20	8.5	15	[illegible]4 $\times 10^{-15}$		-6.4×10^{-15}	-5.2×10^{-15}	-4.1×10^{-15}
$c^{1,8}_{Qq}$	cQq81												
c^8_{tq}	ctq8												
c^8_{Qu}	cQu8												
c^8_{tu}	ctu8												
c^8_{Qd}	cQd8												
c^8_{td}	ctd8												
$c^{3,1}_{Qq}$	cQq13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
$c^{1,1}_{Qq}$	cQq11	0.94	−1.4	−7.7	−5.9	−5	3	5.4					
c^1_{tq}	ctq1	0.65	2.4	−7.9	8.7	0.84	3.7	4.8					
c^1_{Qu}	cQu1	0.57	1.5	−5.2		1.5	2.9	4.3					
c^1_{tu}	ctu1	1.1	−0.29	−3.8		2.3	3.3	6.6					
c^1_{Qd}	cQd1	−0.19	0.55	−4		−0.66	−0.3	−1.4					
c^1_{td}	ctd1	−0.37	−1.3	−5		−0.91	−1.3	−2.1					
$c_{t\varphi}$	ctp		−0.00035	−9.1	−0.034	−0.0093		-1.2×10^2					−68
$c^-_{\varphi Q}$	cpQM	−0.063	1	−41	−0.76	-1×10^2	−0.13	−0.29			21		
$c^3_{\varphi Q}$	cpQ3	0.68	22	0.065	0.46	3.7	1.5	1.8	1.2×10^2	1.2×10^2	2.2×10^2	1.2×10^2	1.3×10^2
$c_{\varphi t}$	cpt	−0.024	2.8	42	−0.36	68	−0.058	−0.16			5.2		
$c_{\varphi tb}$	cptb												
c_{tW}	ctW	0.98	1	−34	13	1.1	69	9.4	84	−76	45	50	9.1×10^2
c_{tZ}	ctZ	−0.54	0.028	27	−0.048	−3.6	−55	−4.3			−10	−6	
c_{bW}	cbW												
c_{tG}	ctG	2.7×10^2	2.5×10^2	3.8×10^2	2.4×10^2	3.1×10^2	2.4×10^2	8.4×10^2		59			
$c^I_{t\varphi}$	ctpI		-7.3×10^{-7}	0.045	−0.00064	−0.00029		0.045					−0.21
$c^I_{\varphi tb}$	cptbI												
c^I_{tW}	ctWI	4.8×10^{-6}	0.032	−1.6	−0.19	0.29	0.91	0.031	1.6×10^{-16}	−1.4	0.47	0.022	−0.13
c^I_{tZ}	ctZI	-1.4×10^{-6}	0.1	−1.2	0.0098	3.2	−0.56	−0.057			−0.87	0.67	
c^I_{bW}	cbWI												
c^I_{tG}	ctGI	−0.00098	0.48	0.66	0.031	−0.7	0.019	−2.4		0.4			
$c^{3(1)}_{Ql}$	cQl31				0.011	0.06				4.1	6		
$c^{-(1)}_{Ql}$	cQlM1				−0.0062	−9.8					2.2		
$c^{(1)}_{Qe}$	cQe1					−1.5					−0.39		
$c^{(1)}_{tl}$	ctl1				−0.0023	−3.6					−0.036		
$c^{(1)}_{te}$	cte1					−6.7					0.064		

12 top processes

$pp \to t\bar t$ $\quad pp \to t\bar t\, b\bar b$ $\quad pp \to t\bar t\, t\bar t$ $\quad pp \to t\bar t\, e^+\nu$ $\quad pp \to t\bar t\, e^+e^-$ $\quad pp \to t\bar t\gamma$

$pp \to t\bar t\, h$ $\quad pp \to tj$ $\quad pp \to t\, e^-\bar\nu$ $\quad pp \to tj\, e^+e^-$ $\quad pp \to tj\gamma$ $\quad pp \to tj\, h$

SMEFTsim validation

1. Internal validation: 2 independent versions (A, B)

2. Validation against `dim6top`

feynrules.irmp.ucl.ac.be/wiki/dim6top – G.Durieux,C.Zhang

Top WG note: Aguilar-Saavedra et al. 1802.07237

$\sigma(\text{int.})/\sigma(\text{SM})$ for $C_i = 1$, $\Lambda = 1$ TeV [permille]

		$pp \to t\bar{t}$	$pp \to t\bar{t}\,b\bar{b}$	$pp \to t\bar{t}\,t\bar{t}$	$pp \to t\bar{t}\,e^+\nu$	$pp \to t\bar{t}\,e^+e^-$	$pp \to t\bar{t}\,\gamma$	$pp \to t\bar{t}\,h$	$pp \to tj$	$pp \to t\,e^-\bar{\nu}$	$pp \to tj\,e^+e^-$	$pp \to tj\,\gamma$	$pp \to tj\,h$
SM	sm	5.2×10^2 pb	1.9 pb	0.0098 pb	0.02 pb	0.016 pb	1.4 pb	0.4 pb	55 pb	2.5 pb	0.0054 pb	0.39 pb	0.016 pb
c_{QQ}^{1}	cQQ1	−0.25	−1.9	-1×10^2		−1.6	−0.67	−0.71					
c_{QQ}^{8}	cQQ8	−0.16	−3.2	−34		−0.91	−0.5	−0.27					
c_{Qt}^{1}	cQt1	−0.15	−5.6	1×10^2		−0.76	−0.19	−0.55					
c_{Qt}^{8}	cQt8	−0.053	−1.8	−41		−0.18	−0.095	−0.15					
c_{Qb}^{1}	cQb1	−0.0055	0.72	−0.052		−0.015	−0.007	−0.026					
c_{Qb}^{8}	cQb8	0.14	3.9	0.12		0.35	0.16	0.56					
c_{tt}^{1}	ctt1			-1.8×10^2									
c_{tb}^{1}	ctb1	−0.0095	0.46	−0.059		−0.02	−0.026	−0.039					
c_{tb}^{8}	ctb8	0.13	3.5	0.11		0.26	0.31	0.56					
c_{QtQb}^{1}	cQtQb1												
c_{QtQb}^{8}	cQtQb8												
c_{QtQb}^{1I}	cQtQb1I												
c_{QtQb}^{8I}	cQtQb8I												
$c_{Qq}^{3,8}$	cQq83	2.7	−0.11	4.7	−85	−20	8.5	15	-3.4×10^{-15}		-6.4×10^{-15}	-5.2×10^{-15}	-4.1×10^{-15}
$c_{Qq}^{1,8}$	cQq81	12	7.1	25	2.6×10^2	71	40	75					
c_{tq}^{8}	ctq8	13	8.2	27	2.6×10^2	62	51	74					
c_{Qu}^{8}	cQu8												
c_{tu}^{8}	ctu8												
c_{Qd}^{8}	cQd8												
c_{td}^{8}	ctd8												
$c_{Qq}^{3,1}$	cQq13												
$c_{Qq}^{1,1}$	cQq11												
c_{tq}^{1}	[illegible]												
c_{Qu}^{1}	[illegible]												
c_{tu}^{1}	ctu												
c_{Qd}^{1}	cQd1												
c_{td}^{1}	ctd1												
$c_{t\varphi}$	ctp												
$c_{\varphi Q}^{-}$	cpQM												
$c_{\varphi Q}^{3}$	cpQ3												
$c_{\varphi t}$	cpt												
$c_{\varphi tb}$	cptb												
c_{tW}	ctW												
c_{tZ}	ctZ												
c_{bW}	cbW												
c_{tG}	ctG												
$c_{t\varphi}^{I}$	ctpI												
$c_{\varphi tb}^{I}$	cptbI												
c_{tW}^{I}	ctWI												
c_{tZ}^{I}	ctZI												
c_{bW}^{I}	cbWI												
c_{tG}^{I}	ctGI												
$c_{Ql}^{3(1)}$	cQl31												
$c_{Ql}^{-(1)}$	cQlM1												
$c_{Qe}^{(1)}$	cQe1					−1.5					−0.39		
$c_{tl}^{(1)}$	ctl1				−0.0023	−3.6					−0.036		
$c_{te}^{(1)}$	cte1					−6.7					0.064		

12 top processes

$\sim$ 50 coefficients

Warsaw basis with specific flavor assumption. e.g.:

$$c_{QQ}^{1} \equiv 2C_{qq}^{1(3333)} - \frac{2}{3}C_{qq}^{3(3333)} \qquad c_{QQ}^{8} \equiv 8C_{qq}^{3(3333)}$$

$$c_{Qt}^{1} \equiv C_{qu}^{1(3333)} \qquad c_{Qt}^{8} \equiv C_{qu}^{8(3333)}$$

$$c_{Qq}^{3,1} \equiv C_{qq}^{3(ii33)} + \frac{1}{6}\left(C_{qq}^{1(i33i)} - C_{qq}^{3(i33i)}\right) \qquad c_{Qq}^{3,8} \equiv C_{qq}^{1(i33i)} - C_{qq}^{3(i33i)}$$

$$c_{Qq}^{1,1} \equiv C_{qq}^{1(ii33)} + \frac{1}{6}C_{qq}^{1(i33i)} + \frac{1}{2}C_{qq}^{3(i33i)} \qquad c_{Qq}^{1,8} \equiv C_{qq}^{1(i33i)} + 3C_{qq}^{3(i33i)}$$

$$c_{t\varphi}^{[I]} \equiv {}^{[Im]}_{Re}\{C_{uH}^{(33)}\} \qquad c_{Hq}^{-} \equiv C_{Hq}^{1(33)} - C_{Hq}^{3(33)}$$

$$c_{HQ}^{3} \equiv C_{Hq}^{3(33)} \qquad c_{Ht} \equiv C_{Hu}^{(33)}$$

SMEFTsim validation

1. Internal validation: 2 independent versions (A, B)

2. Validation against `dim6top`

feynrules.irmp.ucl.ac.be/wiki/dim6top – G.Durieux,C.Zhang

Top WG note: Aguilar-Saavedra et al. 1802.07237

$\sigma(\text{int.})/\sigma(\text{SM})$ for $C_i = 1$, $\Lambda = 1$ TeV [permille]

		$pp \to t\bar{t}$	$pp \to t\bar{t}\,b\bar{b}$	$pp \to t\bar{t}\,t\bar{t}$	$pp \to t\bar{t}\,e^+\nu$	$pp \to t\bar{t}\,e^+e^-$	$pp \to t\bar{t}\,\gamma$	$pp \to t\bar{t}\,h$	$pp \to tj$	$pp \to t\,e^-\bar{\nu}$	$pp \to tj\,e^+e^-$	$pp \to tj\,\gamma$	$pp \to tj\,h$
SM	sm	5.2×10^2 pb	1.9 pb	0.0098 pb	0.02 pb	0.016 pb	1.4 pb	0.4 pb	55 pb	2.5 pb	0.0054 pb	0.39 pb	0.016 pb
c^1_{QQ}	cQQ1	−0.25	−1.9	-1×10^2		−1.6	−0.67	−0.71					
c^8_{QQ}	cQQ8	−0.16	−3.2	−34		−0.91	−0.5	−0.27					
c^1_{Qt}	cQt1	−0.15	−5.6	1×10^2		−0.76	−0.19	−0.55					
c^8_{Qt}	cQt8	−0.053	−1.8	−41		−0.18	−0.095	−0.15					
c^1_{Qb}	cQb1	−0.0055	0.72	−0.052		−0.015	−0.007	−0.026					
c^8_{Qb}	cQb8	0.14	3.9	0.12		0.35	0.16	0.56					
c^1_{tt}	ctt1			-1.8×10^2									
c^1_{tb}	ctb1	−0.0095	0.46	−0.059		−0.02	−0.026	−0.039					
c^8_{tb}	ctb8	0.13	3.5	0.11		0.26	0.31	0.56					
c^1_{QtQb}	cQtQb1												
c^8_{QtQb}	cQtQb8												
c^{1I}_{QtQb}	cQtQb1I												
c^{8I}_{QtQb}	cQtQb8I												
$c^{3,8}_{Qq}$	cQq83	2.7	−0.11	4.7	−85	−20	8.5	15	-3.4×10^{-15}		-6.4×10^{-15}	-5.2×10^{-15}	-4.1×10^{-15}
$c^{1,8}_{Qq}$	cQq81	12	7.1	25	2.6×10^2	71	40	75					
c^8_{tq}	ctq8	13	8.2	27	2.6×10^2	62	51	74					
c^8_{Qu}	cQu8	7.4	4.4	18		21	41	44					
c^8_{tu}	ctu8	7.4	3	16		14	22	45					
c^8_{Qd}	cQd8	5	3	11		17	7.3	29					
c^8_{td}	ctd8	5	2.1	10		12	10	28					
$c^{3,1}_{Qq}$	cQq13	3.3	3	5.8	1.1×10^2	22	11	18	-3.8×10^2		[illegible]		
$c^{1,1}_{Qq}$	cQq11	0.94	−1.4	−7.7	−5.9	−5	3	5.4					
c^1_{tq}	ctq1	0.65	2.4	−7.9	8.7	0.84	3.7	4.8					
c^1_{Qu}	cQu1	0.57	1.5	−5.2		1.5	2.9	4.3					
c^1_{tu}	ctu1	1.1	−0.29	−3.8		2.3	3.3	6.6					
c^1_{Qd}	cQd1	−0.19	0.55	−4		−0.66	−0.3	−1.4					
c^1_{td}	ctd1	−0.37	−1.3	−5		−0.91	−1.3	−2.1					
$c_{t\varphi}$	ctp		−0.00035	−9.1	−0.034	−0.0093		-1.2×10^2					
$c^-_{\varphi Q}$	cpQM	−0.063	1	−41	−0.76	-1×10^2	−0.13	−0.29					
$c^3_{\varphi Q}$	cpQ3	0.68	22	0.065	0.46	3.7	1.5	1.8	1.2×10^2	1.2×10^2	[illegible]		
$c_{\varphi t}$	cpt	−0.024	2.8	42	−0.36	68	−0.058	−0.16					
$c_{\varphi tb}$	cptb												
c_{tW}	ctW	0.98	1	−34	13	1.1	69	9.4	84	−76			
c_{tZ}	ctZ	−0.54	0.028	27	−0.048	−3.6	−55	−4.3			[illegible]	[illegible]	
c_{bW}	cbW												
c_{tG}	ctG	2.7×10^2	2.5×10^2	3.8×10^2	2.4×10^2	3.1×10^2	2.4×10^2	8.4×10^2		59			
$c^I_{t\varphi}$	ctpI		-7.3×10^{-7}	0.045	−0.00064	−0.00029		0.045					−0.21
$c^I_{\varphi tb}$	cptbI												
c^I_{tW}	ctWI	4.8×10^{-6}	0.032	−1.6	−0.19	0.29	0.91	0.031	1.6×10^{-16}	−1.4	0.47	0.022	−0.13
c^I_{tZ}	ctZI	-1.4×10^{-6}	0.1	−1.2	0.0098	3.2	−0.56	−0.057			−0.87	0.67	
c^I_{bW}	cbWI												
c^I_{tG}	ctGI	−0.00098	0.48	0.66	0.031	−0.7	0.019	−2.4		0.4			
$c^{3(1)}_{Ql}$	cQl31				0.011	0.06				4.1	6		
$c^{-(1)}_{Ql}$	cQlM1				−0.0062	−9.8					2.2		
$c^{(1)}_{Qe}$	cQe1					−1.5					−0.39		
$c^{(1)}_{tl}$	ctl1				−0.0023	−3.6					−0.036		
$c^{(1)}_{te}$	cte1					−6.7					0.064		

12 top processes

$\sim$ 50 coefficients

both interference and quadratic terms

$\downarrow$

1200+ numbers compared

SMEFTsim validation

1. Internal validation: 2 independent versions (A, B)

2. Validation against `dim6top`

feynrules.irmp.ucl.ac.be/wiki/dim6top – G.Durieux,C.Zhang
Top WG note: Aguilar-Saavedra et al. 1802.07237

3. Validation against `VBFNLO`

Arnold et al. 0811.4559,1107.4038, Baglio et al 1404.3940
VBSCan Thessaloniki Workshop summary. To appear.

`VBFNLO` has hard coded matrix elements for selected EW processes
uses HISZ basis→ could validate $O_{WWW} = \varepsilon_{ijk} W_\nu^{i\mu} W_\rho^{j\nu} W_\mu^{k\rho}$

checked: $pp \to e^+\nu_e\mu^+\mu^-$ and $pp \to e^+\nu_e\mu^+\nu_\mu jj$

LO, compared σ_{SM} + distributions

✓ $\mathcal{O}_{WWW}$ completes validation for diboson

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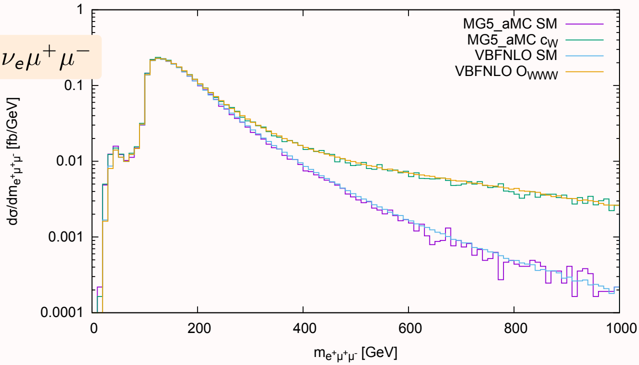
$pp \to e^+ \nu_e \mu^+ \mu^-$



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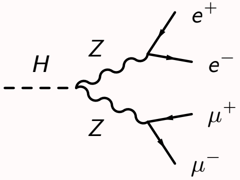
4. Validation against analytic expressions

   Brivio,Trott SMEFT review 1706.08945

Example



	theory	MG interf.	MG full xs
cHW	-0.757133	-0.77948	-0.778724
cHB	-0.217121	-0.223247	-0.223151
cHWB	0.308271	0.295226	0.317418
cHbox	2.	1.99882	2.00469
cHD	0.167224	0.164264	0.170457
cHe	-3.5239	-1.72758	-1.72691
cHl1	4.38291	2.15039	2.14801
cHl3	-1.61513	-3.85776	-3.86201
cll1	2.99835	2.99884	3.00731

$\sigma(\text{int.})/\sigma(\text{SM})$ for $\bar{C}_i = C_i(v/\Lambda)^2 = 1$

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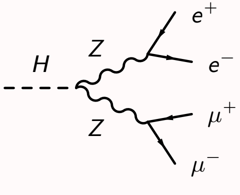

dominant diag. contribution known analytically

	theory	MG interf.	MG full xs
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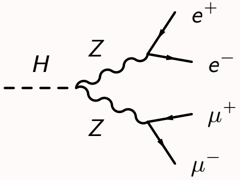

dominant diag. contribution known analytically

MG5: `h > e+ e- mu+ mu- / a`

pure int.

full xsec, linearized

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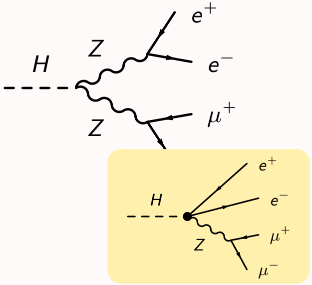

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   VBSCan Thessaloniki Workshop summary. To appear.

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   Brivio,Trott SMEFT review 1706.08945

```
z > e+ e-                        z > u u~
w+ > l+ vl                       w+ > uq dq~

h > a a                          h > z a
h > b b                          h > ta+ ta-
h > e+ e- mu+ mu- / a            h > e+ ve mu- vm
p p > z h / a                    g g > h
p p > w+ h                       p p > w- h
...
```

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   VBSCan Thessaloniki Workshop summary. To appear.

4. Validation against analytic expressions

   Brivio,Trott SMEFT review 1706.08945

5. Further validation still ongoing!

Application: global SMEFT fit

Key features

Brivio,Hays,Trott,Žemaitytė, in preparation

- semianalytic LO corrections **up to** $\mathcal{O}(\boldsymbol{\Lambda}^{-2})$ $\rightarrow$ fully **analytic** χ^2 minimization

- $\#$ parameters controlled by
  - IR symmetries
  - observables (SM selection rules)

Application: global SMEFT fit

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- # parameters controlled by
  - IR symmetries
  - observables (SM selection rules)

	total $N_f = 3$	WZH pole obs.
general	2499	~ 46
MFV	~ 108	~ 30
$U(3)^5$	~ 70	~ 24

Brivio,Jiang,Trott 1709.06492

starting point: **resonant-dominated** processes with $\mathbf{U(3)^5}$

Application: global SMEFT fit

Key features

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- semianalytic LO corrections **up to** $\mathcal{O}(\mathbf{\Lambda^{-2}})$ → fully **analytic** χ^2 minimization
- \# parameters controlled by
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  - observables (SM selection rules)
- combine different **datasets**.

  so far: EWPD + Higgs + diboson (LEP)

  make it extensible: + top + diboson/EW (LHC) + flavor + ...

combining is crucial!

- needed to break degeneracies
- large mixings from RGE between measurements at different energies (e.g. LHC vs flavor)

Application: global SMEFT fit

Key features

Brivio, Hays, Trott, Žemaitytė, in preparation

- semianalytic LO corrections **up to** $\mathcal{O}(\mathbf{\Lambda^{-2}})$ → fully **analytic** χ^2 minimization
- # parameters controlled by
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  - observables (SM selection rules)
- combine different **datasets**.
  so far: EWPD + Higgs + diboson (LEP)
  make it extensible: + top + diboson/EW (LHC) + flavor + ...
- **method**: builds upon
  - Hays, Sanz, Žemaitytė LHCHXSWG-INT-2017-001 (Higgs)
  - ATLAS note: ATL-PHYS-PUB-2017-018
  - Brivio, Trott 1701.06424 (EWPD)
  - Berthier, (Bjørn), Trott 1508.05060, 1606.06693

see also e.g.
Ellis, Murphy, Sanz, You 1803.03252 (with `SMEFTsim`)
Almeida, Alves, Rosa-Agostinho, Éboli, Gonzalez-Garcia 1812.01009

Global fit – 23 relevant operators

Z,W couplings

$$\begin{aligned}
\mathcal{Q}_{Hl}^{(1)} &= (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{l}\gamma^\mu l)\\
\mathcal{Q}_{He} &= (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}\gamma^\mu e)\\
\mathcal{Q}_{Hq}^{(1)} &= (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{q}\gamma^\mu q)\\
\mathcal{Q}_{Hq}^{(3)} &= (iH^\dagger \overleftrightarrow{D}^i_\mu H)(\bar{q}\sigma^i\gamma^\mu q)\\
\mathcal{Q}_{Hu} &= (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}\gamma^\mu u)\\
\mathcal{Q}_{Hd} &= (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}\gamma^\mu d)
\end{aligned}$$

$$\begin{aligned}
\mathcal{Q}_{HD} &= (D_\mu H^\dagger H)(H^\dagger D^\mu H)\\
\mathcal{Q}_{HWB} &= (H^\dagger\sigma^i H)W^i_{\mu\nu}B^{\mu\nu}\\
\mathcal{Q}_{Hl}^{(3)} &= (iH^\dagger \overleftrightarrow{D}^i_\mu H)(\bar{l}\sigma^i\gamma^\mu l)\\
\mathcal{Q}'_{ll} &= (\bar{l}_p\gamma^\mu l_r)(\bar{l}_r\gamma^\mu l_p)
\end{aligned}$$

input quantities

Bhabha scattering

$$\begin{aligned}
\mathcal{Q}_{ee} &= (\bar{e}\gamma^\mu e)(\bar{e}\gamma^\mu e)\\
\mathcal{Q}_{le} &= (\bar{l}\gamma^\mu l)(\bar{e}\gamma^\mu e)\\
\mathcal{Q}_{ll} &= (\bar{l}_p\gamma^\mu l_p)(\bar{l}_r\gamma^\mu l_r)
\end{aligned}$$

$$\begin{aligned}
\mathcal{Q}_{Hbox} &= (H^\dagger H)\,\Box\,(H^\dagger H)\\
\mathcal{Q}_{HG} &= (H^\dagger H)G^a_{\mu\nu}G^{a\mu\nu}\\
\mathcal{Q}_{HB} &= (H^\dagger H)B_{\mu\nu}B^{\mu\nu}\\
\mathcal{Q}_{HW} &= (H^\dagger H)W^i_{\mu\nu}W^{i\mu\nu}\\
\mathcal{Q}_{uH} &= (H^\dagger H)(\bar{q}\tilde{H}u)\\
\mathcal{Q}_{dH} &= (H^\dagger H)(\bar{q}Hd)\\
\mathcal{Q}_{eH} &= (H^\dagger H)(\bar{q}He)\\
\mathcal{Q}_{G} &= \varepsilon_{abc}G^{a\nu}_\mu G^{b\rho}_\nu G^{c\mu}_\rho\\
\mathcal{Q}_{uG} &= (\bar{q}\sigma^{\mu\nu}T^a\tilde{H}u)G^a_{\mu\nu}
\end{aligned}$$

H processes

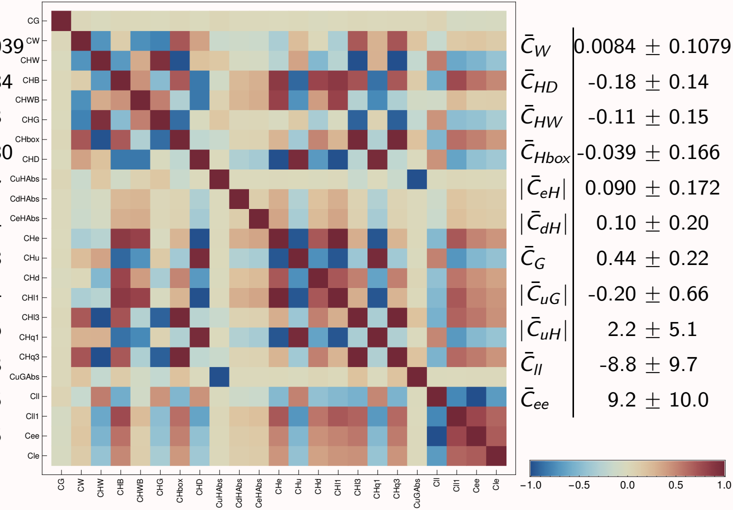
$$\mathcal{Q}_W = \varepsilon_{ijk}W^{i\nu}_\mu W^{j\rho}_\nu W^{k\mu}_\rho$$

TGC

Global fit – results [preliminary]

best fit results for $\bar{C}_i = C_i \frac{v^2}{\Lambda^2}$ from profiling. (ordered by error size)

$\bar{C}_{HG}$	0.00094 ± 0.00039
$\bar{C}'_{ll}$	0.0032 ± 0.0084
$\bar{C}^{(1)}_{Hq}$	-0.017 ± 0.013
$\bar{C}_{Hd}$	0.0016 ± 0.0280
$\bar{C}^{(1)}_{Hl}$	0.050 ± 0.037
$\bar{C}_{HB}$	0.062 ± 0.044
$\bar{C}_{Hu}$	-0.061 ± 0.048
$\bar{C}^{(3)}_{Hl}$	0.042 ± 0.054
$\bar{C}^{(3)}_{Hq}$	0.040 ± 0.056
$\bar{C}_{HWB}$	0.058 ± 0.063
$\bar{C}_{He}$	0.097 ± 0.075
$\bar{C}_{le}$	0.088 ± 0.075



$\bar{C}_{W}$	0.0084 ± 0.1079
$\bar{C}_{HD}$	-0.18 ± 0.14
$\bar{C}_{HW}$	-0.11 ± 0.15
$\bar{C}_{Hbox}$	-0.039 ± 0.166
$\lvert\bar{C}_{eH}\rvert$	0.090 ± 0.172
$\lvert\bar{C}_{dH}\rvert$	0.10 ± 0.20
$\bar{C}_{G}$	0.44 ± 0.22
$\lvert\bar{C}_{uG}\rvert$	-0.20 ± 0.66
$\lvert\bar{C}_{uH}\rvert$	2.2 ± 5.1
$\bar{C}_{ll}$	-8.8 ± 9.7
$\bar{C}_{ee}$	9.2 ± 10.0

Summary & take-home

- The **SMEFT** is a well-defined, general framework for BSM searches

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  - most general BSM characterization (assuming SM sym + fields)
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- The **SMEFT** is a well-defined, general framework for BSM searches
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  - most general BSM characterization (assuming SM sym + fields)
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- SMEFTsim is a powerful tool specifically designed for this purpose @LO
- **Validation** of SMEFTsim has been extensive and is still ongoing
- Global fits can and should be done!
  - starting from flavor symmetric + pole obs: **only** $\sim$ **23** parameters
  - can be systematically extended to other observables and improved with higher orders

Backup slides

The Warsaw basis

Gzadkowski,Iskrzynski,Misiak,Rosiek 1008.4884

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}	$(\bar q_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu\varphi)(\bar u_p\gamma^\mu d_r)$

The Warsaw basis

Gzadkowski,Iskrzynski,Misiak,Rosiek 1008.4884

$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
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}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		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}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\varepsilon_{jk}(\bar{q}_s^k u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j\sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu} u_t)$		

Field redefinitions

Gauge bosons

$$\mathcal{L}_{\rm SMEFT} \supset -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W^I_{\mu\nu}W^{I\mu\nu} - \frac{1}{4}G^a_{\mu\nu}G^{a\mu\nu} +$$
$$+ C_{HB}(H^\dagger H)B_{\mu\nu}B^{\mu\nu} + C_{HW}(H^\dagger H)W^I_{\mu\nu}W^{I\mu\nu} + C_{HWB}(H^\dagger\sigma^I H)W^I_{\mu\nu}B^{\mu\nu}$$
$$+ C_{HG}(H^\dagger H)G^a_{\mu\nu}G^{a\mu\nu}$$

to have **canonically normalized kinetic terms** we need to

1. redefine fields and couplings keeping (gV_μ) unchanged:

$$\begin{aligned} \mathcal{B}_\mu &\to B_\mu(1+C_{HB}v^2) & g_1 &\to g_1(1-C_{HB}v^2) \\ \mathcal{W}^I_\mu &\to W^I_\mu(1+C_{HW}v^2) & g_2 &\to g_2(1-C_{HW}v^2) \\ \mathcal{G}^a_\mu &\to G^a_\mu(1+C_{HG}v^2) & g_s &\to g_s(1-C_{HG}v^2) \end{aligned}$$

2. correct the rotation to mass eigenstates:

$$\begin{pmatrix}\mathcal{W}^3_\mu \\ \mathcal{B}_\mu\end{pmatrix} = \begin{pmatrix} 1 & -v^2 C_{HWB}/2 \\ -v^2 C_{HWB}/2 & 1\end{pmatrix}\begin{pmatrix}\cos\theta & \sin\theta \\ -\sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix}Z_\mu \\ A_\mu\end{pmatrix}$$

(equivalent to a shift of the Weinberg angle)

Grinstein,Wise Phys.Lett.B265(1991)326
Alonso,Jenkins,Manohar,Trott 1312.2014

Field redefinitions

Higgs

$$\mathcal{L}_{\rm SMEFT} \supset \frac{1}{2} D_\mu H^\dagger D^\mu H + C_{H\Box}(H^\dagger H)(H^\dagger \Box H) + C_{HD}(H^\dagger D_\mu H)^*(H^\dagger D^\mu H)$$

to have a canonically normalized kinetic term, in unitary gauge, we need to replace

$$h \to h\left(1 + v^2 C_{H\Box} - \frac{v^2}{4} C_{HD}\right)$$

Alonso,Jenkins,Manohar,Trott 1312.2014

Shifts from input parameters

SM case.

Parameters in the canonically normalized Lagrangian : $\bar{v}, \bar{g}_1, \bar{g}_2, s_{\bar{\theta}}$

The values can be inferred from the measurements e.g. of $\{\alpha_{\rm em}, m_Z, G_f\}$:

$$\alpha_{\rm em} = \frac{\bar{g}_1\bar{g}_2}{\bar{g}_1^2+\bar{g}_2^2} \qquad m_Z = \frac{\bar{g}_2\bar{v}}{2c_{\bar{\theta}}} \qquad G_f = \frac{1}{\sqrt{2}\bar{v}^2}$$

$$\rightarrow$$

$$\hat{v}^2 = \frac{1}{\sqrt{2}G_f}$$
$$\sin\hat{\theta}^2 = \frac{1}{2}\left(1-\sqrt{1-\frac{4\pi\alpha_{\rm em}}{\sqrt{2}G_f m_Z^2}}\right)$$
$$\hat{g}_1 = \frac{\sqrt{4\pi\alpha_{\rm em}}}{\cos\hat{\theta}}$$
$$\hat{g}_2 = \frac{\sqrt{4\pi\alpha_{\rm em}}}{\sin\hat{\theta}}$$

in the SM at tree-level $\bar{\kappa} = \hat{\kappa}$

Shifts from input parameters

SMEFT case.

Parameters in the canonically normalized Lagrangian : $\bar{v}, \bar{g}_1, \bar{g}_2, s_{\bar{\theta}}$

The values can be inferred from the measurements e.g. of $\{\alpha_{\rm em}, m_Z, G_f\}$:

$$\alpha_{\rm em} = \frac{\bar{g}_1\bar{g}_2}{\bar{g}_1^2+\bar{g}_2^2}\left[1+\bar{v}^2 C_{HWB}\frac{\bar{g}_2^3/\bar{g}_1}{\bar{g}_1^2+\bar{g}_2^2}\right]$$
$$m_Z = \frac{\bar{g}_2\bar{v}}{2c_{\bar{\theta}}}+\delta m_Z(C_i)$$
$$G_f = \frac{1}{\sqrt{2}\bar{v}^2}+\delta G_f(C_i)$$

$\rightarrow$

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$$\hat{g}_2 = \frac{\sqrt{4\pi\alpha_{\rm em}}}{\sin\hat{\theta}}$$

in the SM at tree-level $\bar{\kappa} = \hat{\kappa}$

in the SMEFT $\bar{\kappa} = \hat{\kappa}+\delta\kappa(C_i)$

Shifts from input parameters

To have numerical predictions it is necessary to replace $\bar{\kappa} \to \hat{\kappa} + \delta\kappa(C_i)$ for all the parameters in the Lagrangian.

$\{\alpha_{\rm em}, m_Z, G_f\}$ scheme

$$\delta m_Z^2 = m_Z^2 \hat{v}^2 \left(\frac{c_{HD}}{2} + 2 c_{\hat\theta} s_{\hat\theta} c_{HWB}\right)$$

$$\delta G_f = \frac{\hat{v}^2}{\sqrt{2}} \left((c_{Hl}^{(3)})_{11} + (c_{Hl}^{(3)})_{22} - (c_{ll})_{1221}\right)$$

$$\delta g_1 = \frac{s_{\hat\theta}^2}{2(1-2s_{\hat\theta}^2)} \left(\sqrt{2}\delta G_f + \delta m_Z^2/m_Z^2 + 2\frac{c_{\hat\theta}^3}{s_{\hat\theta}} c_{HWB} \hat{v}^2\right)$$

$$\delta g_2 = -\frac{c_{\hat\theta}^2}{2(1-2s_{\hat\theta}^2)} \left(\sqrt{2}\delta G_f + \delta m_Z^2/m_Z^2 + 2\frac{s_{\hat\theta}^3}{c_{\hat\theta}} c_{HWB} \hat{v}^2\right)$$

$$\delta s_\theta^2 = 2 c_{\hat\theta}^2 s_{\hat\theta}^2 (\delta g_1 - \delta g_2) + c_{\hat\theta} s_{\hat\theta} (1 - 2 s_{\hat\theta}^2) c_{HWB} \hat{v}^2$$

$$\delta m_h^2 = m_h^2 \hat{v}^2 \left(2 c_{H\Box} - \frac{c_{HD}}{2} - \frac{3 c_H}{2 lam}\right)$$

Shifts from input parameters

To have numerical predictions it is necessary to replace $\bar{\kappa} \to \hat{\kappa} + \delta\kappa(C_i)$ for all the parameters in the Lagrangian.

$\{m_W, m_Z, G_f\}$ scheme

$$\delta m_Z^2 = m_Z^2 \hat{v}^2 \left(\frac{c_{HD}}{2} + 2c_{\hat{\theta}} s_{\hat{\theta}} c_{HWB}\right)$$

$$\delta G_f = \frac{\hat{v}^2}{\sqrt{2}} \left((c_{Hl}^{(3)})_{11} + (c_{Hl}^{(3)})_{22} - (c_{ll})_{1221}\right)$$

$$\delta g_1 = -\frac{1}{2} \left(\sqrt{2}\delta G_f + \frac{1}{s_{\hat{\theta}}^2} \frac{\delta m_Z^2}{m_Z^2}\right)$$

$$\delta g_2 = -\frac{1}{\sqrt{2}} \delta G_f$$

$$\delta s_\theta^2 = 2c_{\hat{\theta}}^2 s_{\hat{\theta}}^2 (\delta g_1 - \delta g_2) + c_{\hat{\theta}} s_{\hat{\theta}} (1 - 2s_{\hat{\theta}}^2) c_{HWB} \hat{v}^2$$

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Global fit – observables [preliminary]

120 observables included so far

- 10 near-Z-pole EWPO: Γ_Z, $R^0_{\ell,c,b}$, $A_{FB}^{\ell,c,b,\mu,\tau}$, σ^0_h LEPI combination hep-ex/0509008
- 21 distribution bins for bhabha scattering at LEPII LEPII combination 1302.3415
- 74 dist. bins for W^+W^- production at LEPII
  L3: hep-ex/0409016
  OPAL: 0708.1311
  ALEPH: Eur.Phys.J. C38 (2004) 147
  differential combined: 1302.3415
- 15 inclusive obs. for Higgs measurements in $H \to \gamma\gamma$ and $H \to 4\ell$ at LHC
  - ATLAS ($36\ \mathrm{fb}^{-1}$) ATLAS-CONF-2017-047
  - CMS ($36\ \mathrm{fb}^{-1}$) CMS PAS HIG-17-031

Example: dependence for $gg \to h \to 4\ell$

correction to the inclusive rate, relative to the SM
obtained automatically with SMEFTsim

```
1 + 0.0185 * CG + 0.000425 * CHbox -0.0001062 * CHD + 22.3 * CHG
-0.000422 * CuHAbs -0.000425 * CHl3 + 0.000212 * Cll1 + 0.1212 *
CHbox + 0.1193 * CHD + 0.04691 * CHW + 0.01345 * CHB + 0.1284 * CHWB
+ 0.1279 * CHl1 + 0.01765 * CHl3 + 0.003545 * CHe + 0.0925 * Cll +
0.1819 * Cll1 -0.000491 * CHWB + 0.0001946 * CHl1 + 0.001461 * CHl3
+ 0.0001942 * CHe -0.0004985 * CHq1 -0.001724 * CHq3 -0.000259 *
CHu + 0.0001917 * CHd -0.00107 * Cll1 - (0.1166 * CHbox + 0.000747 *
CHD + 1.445 * CHG + 0.01088 * CHW + 0.0001615 * CHB + 0.04346 * CHWB
+ 0.0001276 * CHl1 + 0.000786 * CHl3 + 0.000598 * CHq1 + 0.01186
* CHq3 + 0.0002017 * CHu + 0.0729 * Cll1 + 0.01098 * CHD -0.0706 *
CHWB + 0.0001807 * CdWAbs + 0.02797 * CHl1 + 0.2101 * CHl3 + 0.02792
* CHe -0.0717 * CHq1 -0.2479 * CHq3 -0.03722 * CHu + 0.02755 * CHd
-0.1537 * Cll1 + 0.0002095 * CeWAbs + 0.0003167 * CuWAbs + 2.622 *
CHl3 -2.551 * CHq3 -1.965 * Cll1)
```

- all the relevant operators are included
- only interference is kept → simple **linear** expressions

Global fit to EW precision data - method

Basics of the fit method

Likelihood:

$$L(C_i) = \frac{1}{\sqrt{(2\pi)^n \det V}} \exp\left(-\frac{1}{2}\left(\hat{O}-\bar{O}\right)^T V^{-1}\left(\hat{O}-\bar{O}\right)\right)$$

↓

$$\chi^2 = -2\log L(C_i)$$

→ extract best-fit values on each C_i after profiling the χ^2 over the others

Global fit to EW precision data - method

Likelihood:

$$L(C_i) = \frac{1}{\sqrt{(2\pi)^n \det V}} \exp\left(-\frac{1}{2}\left(\hat{O}-\bar{O}\right)^T V^{-1}\left(\hat{O}-\bar{O}\right)\right)$$

observables (n)

exp. measurement ($\hat{O}$)

SMEFT prediction (C_i) ($\bar{O}$)

covariance matrix (V)

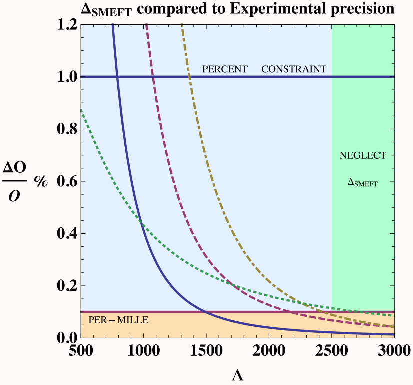
$$V_{i,j} = \Delta_i^{\rm exp}\rho_{ij}^{\rm exp}\Delta_j^{\rm exp} + \Delta_i^{\rm th}\rho_{ij}^{\rm th}\Delta_j^{\rm th}$$

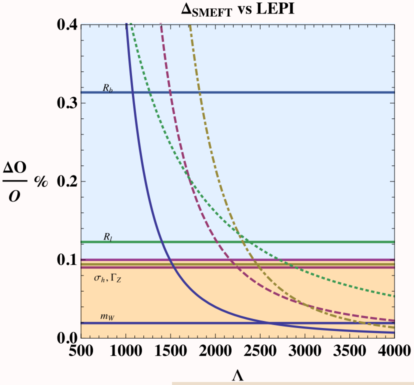
error on O_i ($\Delta_j^{\rm th}$)

correlation mat. ($\rho_{ij}^{\rm th}$)

$$\Delta_i^{\rm th} = \sqrt{\Delta_{i,{\rm SM}}^2 + \Delta_{\rm SMEFT}^2 \bar{O}_i^2}$$

SMEFT uncertainty: → impact of $d \geqslant 8$ operators + radiative corrections
→ initial/final state radiation
→ . . .





Berthier,Trott 1508.05060
Hays,Martin,Sanz,Setford 1808.00442

in the fit: taken to be a fixed flat relative uncertainty $0 \leqslant \Delta_{\rm SMEFT} \leqslant 1\%$

Constructing convenient observables

looking for an optimal set of observables

- only **a few** operators contributing significantly
- many observables **share the same** relevant ops.
- sufficient experimental **sensitivity**

Working assumption:

the dominant effect is the **tree-level interference** $|\mathcal{A}_{SM}\mathcal{A}^*_{d=6}| \sim \frac{C_i}{\Lambda^2}$.

whenever this is suppressed, the coefficient C_i *can be neglected* even if $C_i \neq 0$

- in specific kinematic regions. e.g. for ψ^4 ops. close to W, Z, h **poles**

Constructing convenient observables

Example – close to a pole

Brivio, Jiang, Trott 1709.06492

most ψ^4 operators give diagrams with less resonances

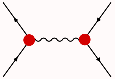
expected to be **suppressed** wrt. "pole operators" by

$$\left(\frac{\Gamma_B m_B}{v^2}\right)^n \sim \begin{array}{ll} 1/300 & (Z,W) \\ 1/10^6 & (h) \end{array}$$

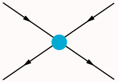
$B = \{Z, W, h\}$

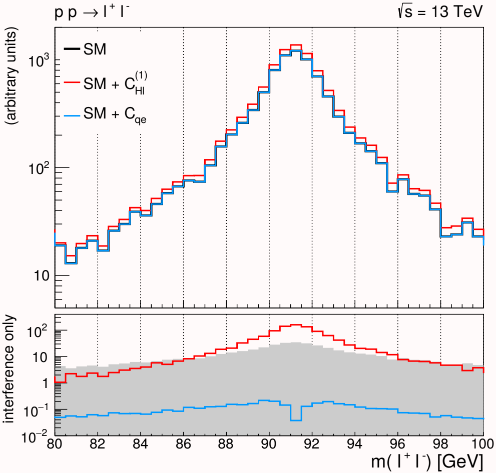
$n = \#$ missing resonances

Drell-Yan via Z resonance ➜



vs.





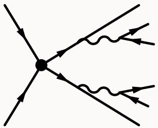
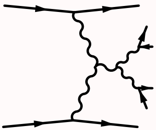
Constructing convenient observables

Example – close to a pole

Brivio,Jiang,Trott 1709.06492

most ψ^4 operators give diagrams with less resonances

! Not *always* the case. The impact must be checked case by case

E.g. VBS  vs 

the 4-fermion diagram is not removed by poles selection.

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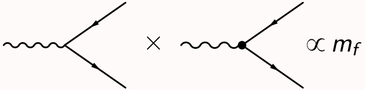
the dominant effect is the **tree-level interference** $|\mathcal{A}_{SM}\mathcal{A}^*_{d=6}| \sim \frac{C_i}{\Lambda^2}$.

whenever this is suppressed, the coefficient C_i *can be neglected* even if $C_i \neq 0$

- in specific kinematic regions. e.g. for ψ^4 ops. close to W, Z, h **poles**
- for operators with interference $\propto m_f$

Example: dipole operators can be neglected for $f \neq t, b$



Constructing convenient observables

looking for an optimal set of observables

- only **a few** operators contributing significantly
- many observables **share the same** relevant ops.
- sufficient experimental **sensitivity**

Working assumption:

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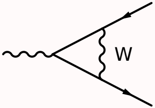
- for operators with interference $\propto m_f$
- for operators inducing FCNC

$\mathcal{A}_{SM}$ is very suppressed:



$\sim \frac{m_j^2 V^*_{jk} V ji}{32\pi^2 m_W^2}$

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- ...

Brivio, Jiang, Trott 1709.06492

	total $N_f = 3$	WZH poles
general	2499	~ 46
MFV	~ 108	~ 30
$U(3)^5$	~ 70	~ 24

The counts reduce significantly!