RGE effects in the SMEFT

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based on 2106.05291

The SMEFT approach

Precision era @LHC with all experimental data consistent with the SM motivates the use of:

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \frac{\mathcal{L}_5}{\Lambda} + \frac{\mathcal{L}_6}{\Lambda^2} + \ldots$$

describing any UV physics at $\Lambda \gg v$

Bases

d=5: Weinberg PRL43(1979)1566
d=6: Buchmller,Wyler Nucl.Phys.B268(1986)621
Grzadkowski et al 1008.4884
d=7: Lehman 1410.4193, Henning,Lu,Melia,Murayama 1512.0343
d=8: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008
Murphy 2005.00059
d=9: Li,Ren,Xiao,Yu,Zheng 2007.07899, Liao,Ma 2007.08125

Anomalous dimensions (d=6)

Alonso,Jenkins,Manohar,Trott 1308.2627,1310.4838,1312.2014
Grojean,Jenkins,Manohar,Trott1301.2588
Alonso,Chang,Jenkins,Manohar,Shotwell 1405.0486
Miro,Ingoldby,Riembau 2005.06983
Baratella,Fernandez,Pomarol 2005.07129,2010.13809

Is dimension-six enough?

- Do not give the main contributions to several observables
- For small values of Λ allowed by data, NLO corrections are mandatory
- To keep up with the precision at the LHC, these corrections are needed too

Signals of the electroweak phase transition at colliders and gravitational wave observatories

Mikael Chala, Claudius Krause, Germano Nardini

EWPD in the SMEFT to dimension eight

Tyler Corbett, Andreas Helset, Adam Martin, Michael Trott

On the impact of dimension-eight SMEFT operators on Higgs measurements

Chris Hays, Adam Martin, Veronica Sanz, Jack Setford

Novel angular dependence in Drell-Yan lepton production via dimension-8 operators

Simone Alioli, Radja Boughezal, Emanuele Mereghetti, Frank Petriello

Probing New Physics in Dimension-8 Neutral Gauge Couplings at e^+e^- Colliders

John Ellis, Hong-Jian He, Rui-Qing Xiao

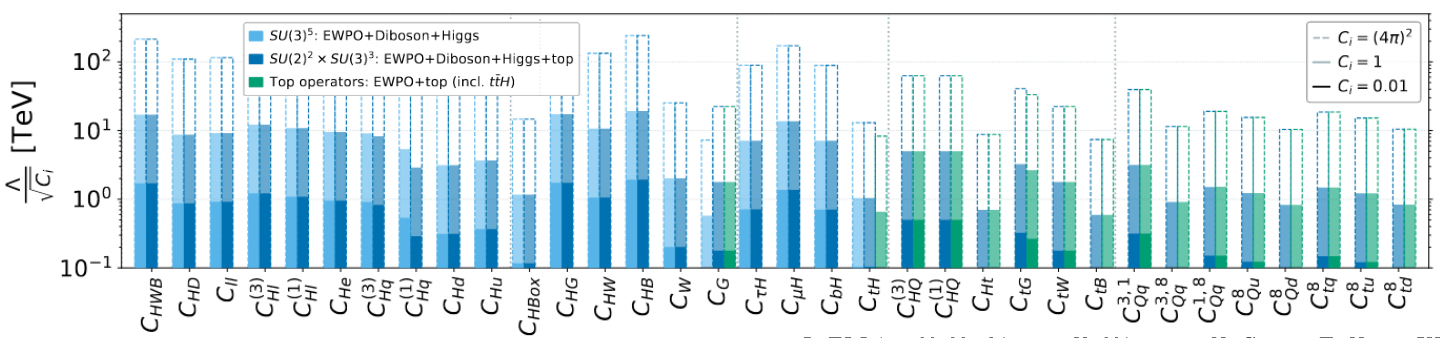
Towards the renormalisation of the Standard Model effective field theory to dimension eight: Bosonic interactions I

M. Chala[1*], G. Guedes[1,2], M. Ramos[1,2], J. Santiago[1]

$$16\pi^2\mu\frac{dc_i^{(8)}}{d\mu} = \gamma_{ij}c_j^{(8)} + \gamma'_{ijk}c_j^{(6)}c_k^{(6)}$$

J.Blas, J.Criado, M.Pérez-Victoria, J.Santiago JHEP03(2018)109

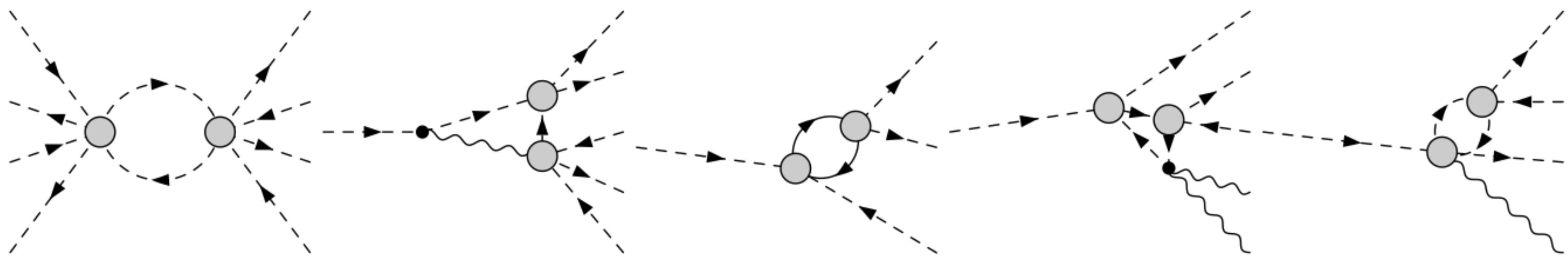
... including only tree level operators from weakly-coupled UV theories



J.Ellis, M.Madigan, K.Mimasu, V.Sanz, T.You JHEP04(2021)279

Theoretical setup

$$\mathcal{L}_{\text{UV}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda^2}\Big\{c_\phi(\phi^\dagger\phi)^3 + c_{\phi\Box}(\phi^\dagger\phi)\Box(\phi^\dagger\phi) + c_{\phi D}(\phi^\dagger D^\mu\phi)^*(\phi^\dagger D_\mu\phi)$$
$$+ c^{(1)}_{\phi\psi_L}(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\overline{\psi_L}\gamma^\mu\psi_L)$$
$$+ c^{(3)}_{\phi\psi_L}(\phi^\dagger i\overleftrightarrow{D}^I_\mu\phi)(\overline{\psi_L}\gamma^\mu\sigma^I\psi_L) + c_{\phi\psi_R}(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\overline{\psi_R}\gamma^\mu\psi_R)$$
$$+ \Big[c_{\phi ud}(\tilde{\phi} iD_\mu\phi)(\overline{u_R}\gamma^\mu d_R) + c_{\psi_R\phi}(\phi^\dagger\phi)\overline{\psi_L}\tilde{\phi}\psi_R + \text{h.c.}\Big]\Big\}$$



$$\mathcal{O} \sim \{\phi^8,\ \phi^6 D^2,\ \phi^4 D^4,\ X^2\phi^4,\ X\phi^4 D^2\}$$

Structure of the RGEs

$\gamma'_{c^{(1)}_{\phi^4}}$	c_ϕ	$c_{\phi D}$	$c_{\phi\Box}$	$c^{(1)}_{\phi\psi_L}$	$c^{(3)}_{\phi\psi_L}$	$c_{\phi\psi_R}$	$c_{\phi ud}$	$c_{\psi_R\phi}$
c_ϕ	0	0	0	0	0	0	0	0
$c_{\phi D}$		$\times$	$\times$	0	0	0	0	0
$c_{\phi\Box}$			$\times$	0	0	0	0	0
$c^{(1)}_{\phi\psi_L}$				$\times$	0	0	0	0
$c^{(3)}_{\phi\psi_L}$					$\times$	0	0	0
$c_{\phi\psi_R}$						$\times$	0	0
$c_{\phi ud}$							$\times$	0
$c_{\psi_R\phi}$								0

$\gamma'_{c^{(1)}_{W^2\phi^4}}$	c_ϕ	$c_{\phi D}$	$c_{\phi\Box}$	$c^{(1)}_{\phi\psi_L}$	$c^{(3)}_{\phi\psi_L}$	$c_{\phi\psi_R}$	$c_{\phi ud}$	$c_{\psi_R\phi}$
c_ϕ	0	0	0	0	0	0	0	0
$c_{\phi D}$		$\times$	$\emptyset$	0	0	0	0	0
$c_{\phi\Box}$			0	0	0	0	0	0
$c^{(1)}_{\phi\psi_L}$				$\times$	0	0	0	0
$c^{(3)}_{\phi\psi_L}$					$\times$	0	0	0
$c_{\phi\psi_R}$						$\times$	0	0
$c_{\phi ud}$							$\times$	0
$c_{\psi_R\phi}$								0

where $\emptyset$ is a zero only in the physical basis.

$$\mathcal{O}^{(1)}_{\phi^4} = (D_\mu\phi^\dagger D_\nu\phi)(D^\nu\phi^\dagger D^\mu\phi) \qquad \mathcal{O}^{(1)}_{W^2\phi^4} = (\phi^\dagger\phi)^2 W^I_{\mu\nu}W^{I\mu\nu}$$

Structure of the RGEs

$\gamma'_{c^{(3)}_{W^2\phi^4}}$	c_ϕ	$c_{\phi D}$	$c_{\phi\Box}$	$c^{(1)}_{\phi\psi_L}$	$c^{(3)}_{\phi\psi_L}$	$c_{\phi\psi_R}$	$c_{\phi ud}$	$c_{\psi_R\phi}$
c_ϕ	0	0	0	0	0	0	0	0
$c_{\phi D}$		$\emptyset$	$\emptyset$	0	0	0	0	0
$c_{\phi\Box}$			0	0	0	0	0	0
$c^{(1)}_{\phi\psi_L}$				$\emptyset$	0	0	0	0
$c^{(3)}_{\phi\psi_L}$					0	0	0	0
$c_{\phi\psi_R}$						$\emptyset$	0	0
$c_{\phi ud}$							$\emptyset$	0
$c_{\psi_R\phi}$								0

$\gamma'_{c^{(1)}_{WB\phi^4}}$	c_ϕ	$c_{\phi D}$	$c_{\phi\Box}$	$c^{(1)}_{\phi\psi_L}$	$c^{(3)}_{\phi\psi_L}$	$c_{\phi\psi_R}$	$c_{\phi ud}$	$c_{\psi_R\phi}$
c_ϕ	0	0	0	0	0	0	0	0
$c_{\phi D}$		$\emptyset$	$\emptyset$	0	0	0	0	0
$c_{\phi\Box}$			0	0	0	0	0	0
$c^{(1)}_{\phi\psi_L}$				$\emptyset$	0	0	0	0
$c^{(3)}_{\phi\psi_L}$					0	0	0	0
$c_{\phi\psi_R}$						$\emptyset$	0	0
$c_{\phi ud}$							$\emptyset$	0
$c_{\psi_R\phi}$								0

where $\emptyset$ is a zero only in the physical basis.

$$\mathcal{O}^{(1)}_{WB\phi^4} = (\phi^\dagger\phi)(\phi^\dagger\sigma^I\phi)W^I_{\mu\nu}B^{\mu\nu} \qquad \mathcal{O}^{(3)}_{W^2\phi^4} = (\phi^\dagger\sigma^I\phi)(\phi^\dagger\sigma^J\phi)W^I_{\mu\nu}W^{J\mu\nu}$$

Consequences

- The operators which are renormalized arise at tree-level in UV completions, in contrast with what is expected from the running triggered by dimension-eight interactions

Mixing ‘‘up’’ and ‘‘to the right’’ between **tree** and **loop** level operators

$\overline{w}$ \ w	0	2	4	6	8
8	X_L^4	$X_L^3H^2$, $X_L^2\psi^2H$, $X_L\psi^4$	$X_L^2H^4$, $X_L\psi^2H^3$, ψ^4H^2	ψ^2H^5	H^8
6		$X_L^2H^2D^2$, $X_L^2\psi\bar{\psi}D$, $X_L\psi^2HD^2$, ψ^4D^2	$X_LH^4D^2$, $X_L^2\bar{\psi}^2H$, $X_L\psi\bar{\psi}H^2D$, $\psi^2H^3D^2$, $X_L\psi^2\bar{\psi}^2$, $\psi^3\bar{\psi}HD$	H^6D^2, $\psi\bar{\psi}H^4D$, $\psi^2\bar{\psi}^2H^2$	$\bar{\psi}^2H^5$
4			$X_L^2X_R^2$, $X_LX_RH^2D^2$, H^4D^4, $X_LX_R\psi\bar{\psi}D$, $X_R\psi^2HD^2$, $X_L\bar{\psi}^2HD^2$, $\psi\bar{\psi}H^2D^3$, $\psi^2\bar{\psi}^2D^2$	$X_RH^4D^2$, $X_R^2\psi^2H$, $X_R\psi\bar{\psi}H^2D$, $\bar{\psi}^2H^3D^2$, $X_R\psi^2\bar{\psi}^2$, $\psi\bar{\psi}^3HD$	$X_R^2H^4$, $X_R\bar{\psi}^2H^3$, $\bar{\psi}^4H^2$
2				$X_R^2H^2D^2$, $X_R^2\psi\bar{\psi}D$, $X_R\bar{\psi}^2HD^2$, $\bar{\psi}^4D^2$	$X_R^3H^2$, $X_R^2\bar{\psi}^2H$, $X_R\bar{\psi}^4$
0					X_R^4

C.Murphy JHEP10(2020)174

Consequences

- The operators which are renormalized arise at tree-level in UV completions
- S and U parameters are not renormalized, at one-loop, by tree-level dimension six interactions:

$$\frac{1}{16\pi}S = \frac{v^2}{\Lambda^2}\left[c_{\phi WB} + c^{(1)}_{WB\phi^4}\frac{v^2}{\Lambda^2}\right], \quad \frac{1}{16\pi}U = \frac{v^4}{\Lambda^4}c^{(3)}_{W^2\phi^4}$$

R.Alonso, E.Jenkins, A.Manohar, M.Trott JHEP04(2014)159

recall

$$\mathcal{O}^{(1)}_{WB\phi^4} = (\phi^\dagger\phi)(\phi^\dagger\sigma^I\phi)W^I_{\mu\nu}B^{\mu\nu}$$
$$\mathcal{O}^{(3)}_{W^2\phi^4} = (\phi^\dagger\sigma^I\phi)(\phi^\dagger\sigma^J\phi)W^I_{\mu\nu}W^{J\mu\nu}$$
$$\mathcal{O}_{\phi WB} = (\phi^\dagger\sigma^I\phi)W^I_{\mu\nu}B^{\mu\nu}$$

Consequences

- The operators which are renormalized arise at tree-level in UV completions
- S and U parameters are not renormalized, at one-loop, by tree-level dimension six interactions
- The contributions triggered by dimension-six terms respect the positivity bounds, with arbitrary Wilson coefficients:

$$16\pi^2 c_{\phi^4}^{(2)} = \frac{1}{3}(5c_{\phi D}^2 + 16 c_{\phi D} c_{\phi\Box} + 16 c_{\phi\Box}^2)\log\frac{M}{\mu} > 0$$

$$16\pi^2 \left[c_{\phi^4}^{(1)} + c_{\phi^4}^{(2)}\right] = \frac{16}{3}(c_{\phi D}^2 - c_{\phi D} c_{\phi\Box} + 2 c_{\phi\Box}^2)\log\frac{M}{\mu} > 0,$$

$$16\pi^2 \left[c_{\phi^4}^{(1)} + c_{\phi^4}^{(2)} + c_{\phi^4}^{(3)}\right] = 3(c_{\phi D}^2 + 8 c_{\phi\Box}^2)\log\frac{M}{\mu} > 0;$$

This holds for contributions from fermionic operators

Consequences

- The operators which are renormalized arise at tree-level in UV completions
- S and U parameters are not renormalized, at one-loop, by tree-level dimension-six interactions
- The contributions triggered by dimension-six terms respect the positivity bounds, with arbitrary Wilson coefficients
- Important corrections to the EW phase transition

$$V \sim -\mu^2|\phi|^2 + \lambda|\phi|^4 + \frac{c_\phi}{\Lambda^2}\left(1 - \frac{108}{16\pi^2}\lambda \log\frac{\Lambda}{v}\right)|\phi|^6 + \frac{126}{16\pi^2\Lambda^4}\log\frac{\Lambda}{v}c_\phi^2\,|\phi|^8$$

EWPT is strong and first order for:

C. Caprini et al. JCAP 03, 024 (2020)

$$1.7\,\text{TeV}^{-2} \lesssim c_\phi \lesssim 3.7\,\text{TeV}^{-2}$$

$$1.5\,\text{TeV}^{-2} \lesssim c_\phi \lesssim 2.6\,\text{TeV}^{-2}$$

Conclusions

- Clear motivations to explore beyond dimension-six interactions
- **We are one step ahead in the renormalization of the SMEFT**
- Many phenomenological consequences show the potential of including both dimension-eight operators and their running in future studies
- Ongoing work to extend our results

Towards the renormalisation of the Standard Model effective field theory to dimension eight: Bosonic interactions I

M. Chala[1*], G. Guedes[1,2], M. Ramos[1,2], J. Santiago[1]

Thank you!

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other consequences

backup

$$\alpha T = -\frac{1}{2}\frac{v^2}{\Lambda^2}\left[c_{\phi D} + c^{(2)}_{\phi^6}\frac{v^2}{\Lambda^2}\right] \quad \text{where} \quad \dot{c}^{(2)}_{\phi^6} \propto c^2_{\phi ud}$$

$$\Rightarrow c_{\phi tb} \leq 5.9 \text{ for } \Lambda = 1\,\text{TeV}$$

Competitive with what was found from top EW interactions
F.Maltoni,L.Mantani,K.Mimasu JHEP10(2019)004

recall

$$\mathcal{O}^{(2)}_{\phi^6} = (\phi^\dagger\phi)(\phi^\dagger\sigma^I\phi)(D_\mu\phi^\dagger\sigma^I D^\mu\phi)$$

$$\mathcal{O}_{\phi D} = (\phi^\dagger D^\mu\phi)^*(\phi^\dagger D_\mu\phi)$$

UV completion in 2106.05291

backup

$$\mathcal{L}_{\rm NP} = \kappa_{\mathcal{S}}\mathcal{S}\phi^\dagger\phi + \lambda_{\mathcal{S}}\mathcal{S}^2\phi^\dagger\phi + \kappa_{\Xi_0}\phi^\dagger\Xi_0^a\sigma_a\phi + \left(\kappa_{\Xi_1}\Xi_1^{a\dagger}\tilde{\phi}^\dagger\sigma_a\phi + {\rm h.c.}\right)$$

$$\frac{c_\phi}{\Lambda^2} = -\lambda_{\mathcal{S}}\frac{\kappa_{\mathcal{S}}^2}{M^4},$$

$$\frac{c_{\phi D}}{\Lambda^2} = \frac{2}{M^4}(2\kappa_{\Xi_1}^2 - \kappa_{\Xi_0}^2),$$

$$\frac{c_{\phi\Box}}{\Lambda^2} = \frac{1}{2M^4}(4\kappa_{\Xi_1}^2 + \kappa_{\Xi_0}^2 - \kappa_{\mathcal{S}}^2)$$

$$\frac{c_{\phi^4}^{(1)}}{\Lambda^4} = 4\frac{\kappa_{\Xi_0}^2}{M^6},$$

$$\frac{c_{\phi^4}^{(2)}}{\Lambda^4} = 8\frac{\kappa_{\Xi_1}^2}{M^6},$$

$$\frac{c_{\phi^4}^{(3)}}{\Lambda^4} = \frac{2}{M^6}(\kappa_{\mathcal{S}}^2 - \kappa_{\Xi_0}^2)$$

Tables of operators

backup

	Operator	Notation	Operator	Notation
ϕ^8	$(\phi^\dagger\phi)^4$	$\mathcal{O}_{\phi^8}$		
$\phi^6 D^2$	$(\phi^\dagger\phi)^2(D_\mu\phi^\dagger D^\mu\phi)$	$\mathcal{O}^{(1)}_{\phi^6}$	$(\phi^\dagger\phi)(\phi^\dagger\sigma^I\phi)(D_\mu\phi^\dagger\sigma^I D^\mu\phi)$	$\mathcal{O}^{(2)}_{\phi^6}$
$\phi^4 D^4$	$(D_\mu\phi^\dagger D_\nu\phi)(D^\nu\phi^\dagger D^\mu\phi)$	$\mathcal{O}^{(1)}_{\phi^4}$	$(D_\mu\phi^\dagger D_\nu\phi)(D^\mu\phi^\dagger D^\nu\phi)$	$\mathcal{O}^{(2)}_{\phi^4}$
	$(D^\mu\phi^\dagger D_\mu\phi)(D^\nu\phi^\dagger D_\nu\phi)$	$\mathcal{O}^{(3)}_{\phi^4}$		
$X^3\phi^2$	$\epsilon^{IJK}(\phi^\dagger\phi)W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	$\mathcal{O}^{(1)}_{W^3\phi^2}$	$\epsilon^{IJK}(\phi^\dagger\phi)W^{I\nu}_{\mu}W^{J\rho}_{\nu}\widetilde{W}^{K\mu}_{\rho}$	$\mathcal{O}^{(2)}_{W^3\phi^2}$
	$\epsilon^{IJK}(\phi^\dagger\sigma^I\phi)B^{\ \nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	$\mathcal{O}^{(1)}_{W^2B\phi^2}$	$\epsilon^{IJK}(\phi^\dagger\sigma^I\phi)(\widetilde{B}^{\mu\nu}W^J_{\nu\rho}W^{K\rho}_{\mu}+B^{\mu\nu}W^J_{\nu\rho}\widetilde{W}^{K\rho}_{\mu})$	$\mathcal{O}^{(2)}_{W^2B\phi^2}$
$X^2\phi^4$	$(\phi^\dagger\phi)^2 G^A_{\mu\nu}G^{A\mu\nu}$	$O^{(1)}_{G^2\phi^4}$	$(\phi^\dagger\phi)^2\widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$	$O^{(2)}_{G^2\phi^4}$
	$(\phi^\dagger\phi)^2 W^I_{\mu\nu}W^{I\mu\nu}$	$\mathcal{O}^{(1)}_{W^2\phi^4}$	$(\phi^\dagger\phi)^2\widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$	$\mathcal{O}^{(2)}_{W^2\phi^4}$
	$(\phi^\dagger\sigma^I\phi)(\phi^\dagger\sigma^J\phi)W^I_{\mu\nu}W^{J\mu\nu}$	$\mathcal{O}^{(3)}_{W^2\phi^4}$	$(\phi^\dagger\sigma^I\phi)(\phi^\dagger\sigma^J\phi)\widetilde{W}^I_{\mu\nu}W^{J\mu\nu}$	$\mathcal{O}^{(4)}_{W^2\phi^4}$
	$(\phi^\dagger\phi)(\phi^\dagger\sigma^I\phi)W^I_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}^{(1)}_{WB\phi^4}$	$(\phi^\dagger\phi)(\phi^\dagger\sigma^I\phi)\widetilde{W}^I_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}^{(2)}_{WB\phi^4}$
	$(\phi^\dagger\phi)^2 B_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}^{(1)}_{B^2\phi^4}$	$(\phi^\dagger\phi)^2\widetilde{B}_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}^{(2)}_{B^2\phi^4}$

Tables of operators backup

$X^2\phi^2D^2$	$(D^\mu\phi^\dagger D^\nu\phi)W^I_{\mu\rho}W^{I\rho}_\nu$	$\mathcal{O}^{(1)}_{W^2\phi^2D^2}$	$(D^\mu\phi^\dagger D_\mu\phi)W^I_{\nu\rho}W^{I\nu\rho}$	$\mathcal{O}^{(2)}_{W^2\phi^2D^2}$
	$(D^\mu\phi^\dagger D_\mu\phi)W^I_{\nu\rho}\widetilde{W}^{I\nu\rho}$	$\mathcal{O}^{(3)}_{W^2\phi^2D^2}$	$i\epsilon^{IJK}(D^\mu\phi^\dagger\sigma^I D^\nu\phi)W^J_{\mu\rho}W^{K\rho}_\nu$	$\mathcal{O}^{(4)}_{W^2\phi^2D^2}$
	$\epsilon^{IJK}(D^\mu\phi^\dagger\sigma^I D^\nu\phi)(W^J_{\mu\rho}\widetilde{W}^{K\rho}_\nu - \widetilde{W}^J_{\mu\rho}W^{K\rho}_\nu)$	$\mathcal{O}^{(5)}_{W^2\phi^2D^2}$	$i\epsilon^{IJK}(D^\mu\phi^\dagger\sigma^I D^\nu\phi)(W^J_{\mu\rho}\widetilde{W}^{K\rho}_\nu + \widetilde{W}^J_{\mu\rho}W^{K\rho}_\nu)$	$\mathcal{O}^{(6)}_{W^2\phi^2D^2}$
	$(D^\mu\phi^\dagger\sigma^I D_\mu\phi)B_{\nu\rho}W^{I\nu\rho}$	$\mathcal{O}^{(1)}_{WB\phi^2D^2}$	$(D^\mu\phi^\dagger\sigma^I D_\mu\phi)B_{\nu\rho}\widetilde{W}^{I\nu\rho}$	$\mathcal{O}^{(2)}_{WB\phi^2D^2}$
	$i(D^\mu\phi^\dagger\sigma^I D^\nu\phi)(B_{\mu\rho}W^{I\rho}_\nu - B_{\nu\rho}W^{I\rho}_\mu)$	$\mathcal{O}^{(3)}_{WB\phi^2D^2}$	$(D^\mu\phi^\dagger\sigma^I D^\nu\phi)(B_{\mu\rho}W^{I\rho}_\nu + B_{\nu\rho}W^{I\rho}_\mu)$	$\mathcal{O}^{(4)}_{WB\phi^2D^2}$
	$i(D^\mu\phi^\dagger\sigma^I D^\nu\phi)(B_{\mu\rho}\widetilde{W}^{I\rho}_\nu - B_{\nu\rho}\widetilde{W}^{I\rho}_\mu)$	$\mathcal{O}^{(5)}_{WB\phi^2D^2}$	$(D^\mu\phi^\dagger\sigma^I D^\nu\phi)(B_{\mu\rho}\widetilde{W}^{I\rho}_\nu + B_{\nu\rho}\widetilde{W}^{I\rho}_\mu)$	$\mathcal{O}^{(6)}_{WB\phi^2D^2}$
	$(D^\mu\phi^\dagger D^\nu\phi)B_{\mu\rho}B_\nu^{\ \rho}$	$\mathcal{O}^{(1)}_{B^2\phi^2D^2}$	$(D^\mu\phi^\dagger D_\mu\phi)B_{\nu\rho}B^{\nu\rho}$	$\mathcal{O}^{(2)}_{B^2\phi^2D^2}$
	$(D^\mu\phi^\dagger D_\mu\phi)B_{\nu\rho}\widetilde{B}^{\nu\rho}$	$\mathcal{O}^{(3)}_{B^2\phi^2D^2}$		
$X\phi^4D^2$	$i(\phi^\dagger\phi)(D^\mu\phi^\dagger\sigma^I D^\nu\phi)W^I_{\mu\nu}$	$\mathcal{O}^{(1)}_{W\phi^4D^2}$	$i(\phi^\dagger\phi)(D^\mu\phi^\dagger\sigma^I D^\nu\phi)\widetilde{W}^I_{\mu\nu}$	$\mathcal{O}^{(2)}_{W\phi^4D^2}$
	$i\epsilon^{IJK}(\phi^\dagger\sigma^I\phi)(D^\mu\phi^\dagger\sigma^J D^\nu\phi)W^K_{\mu\nu}$	$\mathcal{O}^{(3)}_{W\phi^4D^2}$	$i\epsilon^{IJK}(\phi^\dagger\sigma^I\phi)(D^\mu\phi^\dagger\sigma^J D^\nu\phi)\widetilde{W}^K_{\mu\nu}$	$\mathcal{O}^{(4)}_{W\phi^4D^2}$
	$i(\phi^\dagger\phi)(D^\mu\phi^\dagger D^\nu\phi)B_{\mu\nu}$	$\mathcal{O}^{(1)}_{B\phi^4D^2}$	$i(\phi^\dagger\phi)(D^\mu\phi^\dagger D^\nu\phi)\widetilde{B}_{\mu\nu}$	$\mathcal{O}^{(2)}_{B\phi^4D^2}$

Tables of operators

backup

	Operator	Notation	Operator	Notation
$\boldsymbol{\phi^2 D^4}$	$(D_\mu D^\mu \phi^\dagger)(D_\nu D^\nu \phi)$	$\mathcal{O}_{D\phi}$		
$\boldsymbol{\phi^4 D^2}$	$(\phi^\dagger \phi)(D_\mu \phi)^\dagger (D^\mu \phi)$	$\mathcal{O}'_{\phi D}$	$(\phi^\dagger \phi) D^\mu (\phi^\dagger \mathrm{i} \overleftrightarrow{D}_\mu \phi)$	$\mathcal{O}''_{\phi D}$
$\boldsymbol{X \phi^2 D^2}$	$D_\nu W^{I\mu\nu} (\phi^\dagger \mathrm{i} \overleftrightarrow{D}^I_\mu \phi)$	$\mathcal{O}_{WD\phi}$	$\partial_\nu B^{\mu\nu} (\phi^\dagger \mathrm{i} \overleftrightarrow{D}_\mu \phi)$	$\mathcal{O}_{BD\phi}$