SMEFT vs HEFT
for new physics searches at LHC

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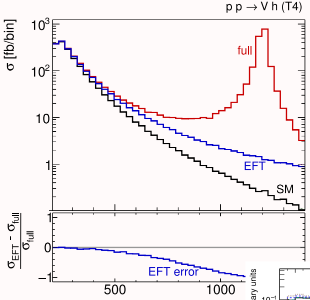
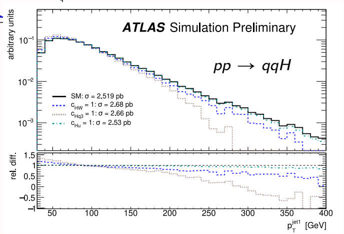
Effective Field Theories for BSM physics

SM extensions that parameterize **small deviations** from SM predictions

→ "indirect searches" of New Physics at LHC and precision exp.



adapted from Brehmer et al 1510.03443



ATL-PHYS-PUB-2019-042

Plan of the talk

1. introducing SMEFT and HEFT
2. SMEFT vs HEFT: comparing **truncated EFTs**
3. SMEFT vs HEFT: comparing EFTs **at all orders**
4. alternative approaches: primaries, pseudo-observables...

The Standard Model Effective Field Theory – SMEFT

promoting the Standard Model to an EFT → add **higher-dimensional** terms made of SM **fields** and respecting the SM **symmetries**

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \frac{1}{\Lambda^3}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \dots \qquad \mathcal{L}_d = \sum_i C_i \mathcal{O}_i^{(d)}$$

C_i = Wilson coefficients

$\mathcal{O}_i^{(d)}$ = gauge-invariant operators forming a basis: a complete, non-redundant set

Buchmüller,Wyler 1986

- matches BSM theories that live at $\Lambda \gg v$ and that fall exactly onto SM in low-E limit
- a complete catalogue of BSM effects compatible with SM symmetry structure
- **power counting**: expected size of BSM effects $\sim$ operator dimension in first approx

SMEFT at $d = 6$: the 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	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star \left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p d_r \varphi)$
$Q_{\widetilde W}$	$\varepsilon^{IJK} \widetilde W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G_{\mu\nu}^A G^{A\mu\nu}$	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}	$(\bar q_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu\varphi)(\bar u_p \gamma^\mu d_r)$

Grzadkowski,Iskrzynski,Misiak,Rosiek 1008.4884

SMEFT at $d = 6$: the Warsaw basis

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

Grzadkowski,Iskrzynski,Misiak,Rosiek 1008.4884

SMEFT at $d = 8$: Murphy basis

Murphy 2206.07722
see also: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008

$1: X^4,\ X^3X'$

$Q_{G^4}^{(1)}$	$(G_{\mu\nu}^A G^{A\mu\nu})(G_{\rho\sigma}^B G^{B\rho\sigma})$
$Q_{G^4}^{(2)}$	$(G_{\mu\nu}^A \widetilde{G}^{A\mu\nu})(G_{\rho\sigma}^B \widetilde{G}^{B\rho\sigma})$
$Q_{G^4}^{(3)}$	$(G_{\mu\nu}^A G^{B\mu\nu})(G_{\rho\sigma}^A G^{B\rho\sigma})$
$Q_{G^4}^{(4)}$	$(G_{\mu\nu}^A \widetilde{G}^{B\mu\nu})(G_{\rho\sigma}^A \widetilde{G}^{B\rho\sigma})$
$Q_{G^4}^{(5)}$	$(G_{\mu\nu}^A G^{A\mu\nu})(G_{\rho\sigma}^B \widetilde{G}^{B\rho\sigma})$
$Q_{G^4}^{(6)}$	$(G_{\mu\nu}^A G^{B\mu\nu})(G_{\rho\sigma}^A \widetilde{G}^{B\rho\sigma})$
$Q_{G^4}^{(7)}$	$d^{ABE}d^{CDE}(G_{\mu\nu}^A G^{B\mu\nu})(G_{\rho\sigma}^C G^{D\rho\sigma})$
$Q_{G^4}^{(8)}$	$d^{ABE}d^{CDE}(G_{\mu\nu}^A \widetilde{G}^{B\mu\nu})(G_{\rho\sigma}^C \widetilde{G}^{D\rho\sigma})$
$Q_{G^4}^{(9)}$	$d^{ABE}d^{CDE}(G_{\mu\nu}^A G^{B\mu\nu})(G_{\rho\sigma}^C \widetilde{G}^{D\rho\sigma})$
$Q_{W^4}^{(1)}$	$(W_{\mu\nu}^I W^{I\mu\nu})(W_{\rho\sigma}^J W^{J\rho\sigma})$
$Q_{W^4}^{(2)}$	$(W_{\mu\nu}^I \widetilde{W}^{I\mu\nu})(W_{\rho\sigma}^J \widetilde{W}^{J\rho\sigma})$
$Q_{W^4}^{(3)}$	$(W_{\mu\nu}^I W^{J\mu\nu})(W_{\rho\sigma}^I W^{J\rho\sigma})$
$Q_{W^4}^{(4)}$	$(W_{\mu\nu}^I \widetilde{W}^{J\mu\nu})(W_{\rho\sigma}^I \widetilde{W}^{J\rho\sigma})$
$Q_{W^4}^{(5)}$	$(W_{\mu\nu}^I W^{I\mu\nu})(W_{\rho\sigma}^J \widetilde{W}^{J\rho\sigma})$
$Q_{W^4}^{(6)}$	$(W_{\mu\nu}^I W^{J\mu\nu})(W_{\rho\sigma}^I \widetilde{W}^{J\rho\sigma})$
$Q_{B^4}^{(1)}$	$(B_{\mu\nu}B^{\mu\nu})(B_{\rho\sigma}B^{\rho\sigma})$
$Q_{B^4}^{(2)}$	$(B_{\mu\nu}\widetilde{B}^{\mu\nu})(B_{\rho\sigma}\widetilde{B}^{\rho\sigma})$
$Q_{B^4}^{(3)}$	$(B_{\mu\nu}B^{\mu\nu})(B_{\rho\sigma}\widetilde{B}^{\rho\sigma})$
$Q_{G^3B}^{(1)}$	$d^{ABC}(B_{\mu\nu}G^{A\mu\nu})(G_{\rho\sigma}^B G^{C\rho\sigma})$
$Q_{G^3B}^{(2)}$	$d^{ABC}(B_{\mu\nu}\widetilde{G}^{A\mu\nu})(G_{\rho\sigma}^B \widetilde{G}^{C\rho\sigma})$
$Q_{G^3B}^{(3)}$	$d^{ABC}(B_{\mu\nu}\widetilde{G}^{A\mu\nu})(G_{\rho\sigma}^B G^{C\rho\sigma})$
$Q_{G^3B}^{(4)}$	$d^{ABC}(B_{\mu\nu}G^{A\mu\nu})(G_{\rho\sigma}^B \widetilde{G}^{C\rho\sigma})$

$1: X^2X'^2$

$Q_{G^2W^2}^{(1)}$	$(W_{\mu\nu}^I W^{I\mu\nu})(G_{\rho\sigma}^A G^{A\rho\sigma})$
$Q_{G^2W^2}^{(2)}$	$(W_{\mu\nu}^I \widetilde{W}^{I\mu\nu})(G_{\rho\sigma}^A \widetilde{G}^{A\rho\sigma})$
$Q_{G^2W^2}^{(3)}$	$(W_{\mu\nu}^I G^{A\mu\nu})(W_{\rho\sigma}^I G^{A\rho\sigma})$
$Q_{G^2W^2}^{(4)}$	$(W_{\mu\nu}^I \widetilde{G}^{A\mu\nu})(W_{\rho\sigma}^I \widetilde{G}^{A\rho\sigma})$
$Q_{G^2W^2}^{(5)}$	$(W_{\mu\nu}^I \widetilde{W}^{I\mu\nu})(G_{\rho\sigma}^A G^{A\rho\sigma})$
$Q_{G^2W^2}^{(6)}$	$(W_{\mu\nu}^I W^{I\mu\nu})(G_{\rho\sigma}^A \widetilde{G}^{A\rho\sigma})$
$Q_{G^2W^2}^{(7)}$	$(W_{\mu\nu}^I G^{A\mu\nu})(W_{\rho\sigma}^I \widetilde{G}^{A\rho\sigma})$
$Q_{G^2B^2}^{(1)}$	$(B_{\mu\nu}B^{\mu\nu})(G_{\rho\sigma}^A G^{A\rho\sigma})$
$Q_{G^2B^2}^{(2)}$	$(B_{\mu\nu}\widetilde{B}^{\mu\nu})(G_{\rho\sigma}^A \widetilde{G}^{A\rho\sigma})$
$Q_{G^2B^2}^{(3)}$	$(B_{\mu\nu}G^{A\mu\nu})(B_{\rho\sigma}G^{A\rho\sigma})$
$Q_{G^2B^2}^{(4)}$	$(B_{\mu\nu}\widetilde{G}^{A\mu\nu})(B_{\rho\sigma}\widetilde{G}^{A\rho\sigma})$
$Q_{G^2B^2}^{(5)}$	$(B_{\mu\nu}\widetilde{B}^{\mu\nu})(G_{\rho\sigma}^A G^{A\rho\sigma})$
$Q_{G^2B^2}^{(6)}$	$(B_{\mu\nu}B^{\mu\nu})(G_{\rho\sigma}^A \widetilde{G}^{A\rho\sigma})$
$Q_{G^2B^2}^{(7)}$	$(B_{\mu\nu}G^{A\mu\nu})(B_{\rho\sigma}\widetilde{G}^{A\rho\sigma})$
$Q_{W^2B^2}^{(1)}$	$(B_{\mu\nu}B^{\mu\nu})(W_{\rho\sigma}^I W^{I\rho\sigma})$
$Q_{W^2B^2}^{(2)}$	$(B_{\mu\nu}\widetilde{B}^{\mu\nu})(W_{\rho\sigma}^I \widetilde{W}^{I\rho\sigma})$
$Q_{W^2B^2}^{(3)}$	$(B_{\mu\nu}W^{I\mu\nu})(B_{\rho\sigma}W^{I\rho\sigma})$
$Q_{W^2B^2}^{(4)}$	$(B_{\mu\nu}\widetilde{W}^{I\mu\nu})(B_{\rho\sigma}\widetilde{W}^{I\rho\sigma})$
$Q_{W^2B^2}^{(5)}$	$(B_{\mu\nu}\widetilde{B}^{\mu\nu})(W_{\rho\sigma}^I W^{I\rho\sigma})$
$Q_{W^2B^2}^{(6)}$	$(B_{\mu\nu}B^{\mu\nu})(W_{\rho\sigma}^I \widetilde{W}^{I\rho\sigma})$
$Q_{W^2B^2}^{(7)}$	$(B_{\mu\nu}W^{I\mu\nu})(B_{\rho\sigma}\widetilde{W}^{I\rho\sigma})$

$2: H^8$

Q_{H^8}	$(H^\dagger H)^4$

$3: H^6D^2$

$Q_{H^6}^{(1)}$	$(H^\dagger H)^2(D_\mu H^\dagger D^\mu H)$
$Q_{H^6}^{(2)}$	$(H^\dagger H)(H^\dagger \tau^I H)(D_\mu H^\dagger \tau^I D^\mu H)$

$4: H^4D^4$

$Q_{H^4}^{(1)}$	$(D_\mu H^\dagger D_\nu H)(D^\nu H^\dagger D^\mu H)$
$Q_{H^4}^{(2)}$	$(D_\mu H^\dagger D_\nu H)(D^\mu H^\dagger D^\nu H)$
$Q_{H^4}^{(3)}$	$(D^\mu H^\dagger D_\mu H)(D^\nu H^\dagger D_\nu H)$

$5: X^3H^2$

$Q_{G^3H^2}^{(1)}$	$f^{ABC}(H^\dagger H)G_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$
$Q_{G^3H^2}^{(2)}$	$f^{ABC}(H^\dagger H)G_\mu^{A\nu}G_\nu^{B\rho}\widetilde{G}_\rho^{C\mu}$
$Q_{W^3H^2}^{(1)}$	$\epsilon^{IJK}(H^\dagger H)W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$
$Q_{W^3H^2}^{(2)}$	$\epsilon^{IJK}(H^\dagger H)W_\mu^{I\nu}W_\nu^{J\rho}\widetilde{W}_\rho^{K\mu}$
$Q_{W^2BH^2}^{(1)}$	$\epsilon^{IJK}(H^\dagger \tau^I H)B_\mu^{\ \nu}W_\nu^{J\rho}W_\rho^{K\mu}$
$Q_{W^2BH^2}^{(2)}$	$\epsilon^{IJK}(H^\dagger \tau^I H)(\widetilde{B}^{\mu\nu}W_{\nu\rho}^J W_\mu^{K\rho} + B^{\mu\nu}W_{\nu\rho}^J \widetilde{W}_\mu^{K\rho})$

$6: X^2H^4$

$Q_{G^2H^4}^{(1)}$	$(H^\dagger H)^2 G_{\mu\nu}^A G^{A\mu\nu}$
$Q_{G^2H^4}^{(2)}$	$(H^\dagger H)^2 \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$
$Q_{W^2H^4}^{(1)}$	$(H^\dagger H)^2 W_{\mu\nu}^I W^{I\mu\nu}$
$Q_{W^2H^4}^{(2)}$	$(H^\dagger H)^2 \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$
$Q_{W^2H^4}^{(3)}$	$(H^\dagger \tau^I H)(H^\dagger \tau^J H)W_{\mu\nu}^I W^{J\mu\nu}$
$Q_{W^2H^4}^{(4)}$	$(H^\dagger \tau^I H)(H^\dagger \tau^J H)\widetilde{W}_{\mu\nu}^I W^{J\mu\nu}$
$Q_{WBH^4}^{(1)}$	$(H^\dagger H)(H^\dagger \tau^I H)W_{\mu\nu}^I B^{\mu\nu}$
$Q_{WBH^4}^{(2)}$	$(H^\dagger H)(H^\dagger \tau^I H)\widetilde{W}_{\mu\nu}^I B^{\mu\nu}$
$Q_{B^2H^4}^{(1)}$	$(H^\dagger H)^2 B_{\mu\nu}B^{\mu\nu}$
$Q_{B^2H^4}^{(2)}$	$(H^\dagger H)^2 \widetilde{B}_{\mu\nu}B^{\mu\nu}$

$7: X^2H^2D^2$

$Q_{G^2H^2D^2}^{(1)}$	$(D^\mu H^\dagger D^\nu H)G_{\mu\rho}^A G_\nu^{A\rho}$
$Q_{G^2H^2D^2}^{(2)}$	$(D^\mu H^\dagger D_\mu H)G_{\nu\rho}^A G^{A\nu\rho}$
$Q_{G^2H^2D^2}^{(3)}$	$(D^\mu H^\dagger D_\mu H)G_{\nu\rho}^A \widetilde{G}^{A\nu\rho}$
$Q_{W^2H^2D^2}^{(1)}$	$(D^\mu H^\dagger D^\nu H)W_{\mu\rho}^I W_\nu^{I\rho}$
$Q_{W^2H^2D^2}^{(2)}$	$(D^\mu H^\dagger D_\mu H)W_{\nu\rho}^I W^{I\nu\rho}$
$Q_{W^2H^2D^2}^{(3)}$	$(D^\mu H^\dagger D_\mu H)W_{\nu\rho}^I \widetilde{W}^{I\nu\rho}$
$Q_{W^2H^2D^2}^{(4)}$	$i\epsilon^{IJK}(D^\mu H^\dagger \tau^I D^\nu H)W_{\mu\rho}^J W_\nu^{K\rho}$
$Q_{W^2H^2D^2}^{(5)}$	$\epsilon^{IJK}(D^\mu H^\dagger \tau^I D^\nu H)(W_{\mu\rho}^J \widetilde{W}_\nu^{K\rho} - \widetilde{W}_{\mu\rho}^J W_\nu^{K\rho})$
$Q_{W^2H^2D^2}^{(6)}$	$i\epsilon^{IJK}(D^\mu H^\dagger \tau^I D^\nu H)(W_{\mu\rho}^J \widetilde{W}_\nu^{K\rho} + \widetilde{W}_{\mu\rho}^J W_\nu^{K\rho})$
$Q_{WBH^2D^2}^{(1)}$	$(D^\mu H^\dagger \tau^I D_\mu H)B_{\nu\rho}W^{I\nu\rho}$
$Q_{WBH^2D^2}^{(2)}$	$(D^\mu H^\dagger \tau^I D_\mu H)B_{\nu\rho}\widetilde{W}^{I\nu\rho}$
$Q_{WBH^2D^2}^{(3)}$	$i(D^\mu H^\dagger \tau^I D^\nu H)(B_{\mu\rho}W_\nu^{I\rho} - B_{\nu\rho}W_\mu^{I\rho})$
$Q_{WBH^2D^2}^{(4)}$	$(D^\mu H^\dagger \tau^I D^\nu H)(B_{\mu\rho}W_\nu^{I\rho} + B_{\nu\rho}W_\mu^{I\rho})$
$Q_{WBH^2D^2}^{(5)}$	$i(D^\mu H^\dagger \tau^I D^\nu H)(B_{\mu\rho}\widetilde{W}_\nu^{I\rho} - B_{\nu\rho}\widetilde{W}_\mu^{I\rho})$
$Q_{WBH^2D^2}^{(6)}$	$(D^\mu H^\dagger \tau^I D^\nu H)(B_{\mu\rho}\widetilde{W}_\nu^{I\rho} + B_{\nu\rho}\widetilde{W}_\mu^{I\rho})$
$Q_{B^2H^2D^2}^{(1)}$	$(D^\mu H^\dagger D^\nu H)B_{\mu\rho}B_\nu^{\ \rho}$
$Q_{B^2H^2D^2}^{(2)}$	$(D^\mu H^\dagger D_\mu H)B_{\nu\rho}B^{\nu\rho}$
$Q_{B^2H^2D^2}^{(3)}$	$(D^\mu H^\dagger D_\mu H)B_{\nu\rho}\widetilde{B}^{\nu\rho}$

$8: XH^4D^2$

$Q_{WH^4D^2}^{(1)}$	$(H^\dagger H)(D^\mu H^\dagger \tau^I D^\nu H)W_{\mu\nu}^I$
$Q_{WH^4D^2}^{(2)}$	$(H^\dagger H)(D^\mu H^\dagger \tau^I D^\nu H)\widetilde{W}_{\mu\nu}^I$
$Q_{WH^4D^2}^{(3)}$	$\epsilon^{IJK}(H^\dagger \tau^I H)(D^\mu H^\dagger \tau^J D^\nu H)W_{\mu\nu}^K$
$Q_{WH^4D^2}^{(4)}$	$\epsilon^{IJK}(H^\dagger \tau^I H)(D^\mu H^\dagger \tau^J D^\nu H)\widetilde{W}_{\mu\nu}^K$
$Q_{BH^4D^2}^{(1)}$	$(H^\dagger H)(D^\mu H^\dagger D^\nu H)B_{\mu\nu}$
$Q_{BH^4D^2}^{(2)}$	$(H^\dagger H)(D^\mu H^\dagger D^\nu H)\widetilde{B}_{\mu\nu}$

SMEFT at $d=8$: Murphy basis

Murphy 2206.07722
see also: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008

$9:\psi^2X^2H+\text{h.c.}$	
$Q^{(1)}_{leG^2H}$	$(\bar l_p e_r)HG^A_{\mu\nu}G^{A\mu\nu}$
$Q^{(2)}_{leG^2H}$	$(\bar l_p e_r)H\widetilde G^A_{\mu\nu}G^{A\mu\nu}$
$Q^{(1)}_{leW^2H}$	$(\bar l_p e_r)HW^I_{\mu\nu}W^{I\mu\nu}$
$Q^{(2)}_{leW^2H}$	$(\bar l_p e_r)H\widetilde W^I_{\mu\nu}W^{I\mu\nu}$
$Q^{(3)}_{leW^2H}$	$\epsilon^{IJK}(\bar l_p\sigma^{\mu\nu}e_r)\tau^I HW^J_{\mu\rho}W^{K\rho}_{\nu}$
$Q^{(1)}_{quG^2H}$	$(\bar q_p u_r)\widetilde HG^A_{\mu\nu}G^{A\mu\nu}$
$Q^{(2)}_{quG^2H}$	$(\bar q_p u_r)\widetilde H\widetilde G^A_{\mu\nu}G^{A\mu\nu}$
$Q^{(3)}_{quG^2H}$	$d^{ABC}(\bar q_p T^A u_r)\widetilde HG^B_{\mu\nu}G^{C\mu\nu}$
$Q^{(4)}_{quG^2H}$	$d^{ABC}(\bar q_p T^A u_r)\widetilde H\widetilde G^B_{\mu\nu}G^{C\mu\nu}$
$Q^{(5)}_{quG^2H}$	$f^{ABC}(\bar q_p\sigma^{\mu\nu}T^A u_r)\widetilde HG^B_{\mu\rho}G^{C\rho}_{\nu}$
$Q^{(1)}_{quGWH}$	$(\bar q_p T^A u_r)\tau^I\widetilde HG^A_{\mu\nu}W^{I\mu\nu}$
$Q^{(2)}_{quGWH}$	$(\bar q_p T^A u_r)\tau^I\widetilde H\widetilde G^A_{\mu\nu}W^{I\mu\nu}$
$Q^{(3)}_{quGWH}$	$(\bar q_p\sigma^{\mu\nu}T^A u_r)\tau^I\widetilde HG^A_{\mu\rho}W^{I\rho}_{\nu}$
$Q^{(1)}_{quGBH}$	$(\bar q_p T^A u_r)\widetilde HG^A_{\mu\nu}B^{\mu\nu}$
$Q^{(2)}_{quGBH}$	$(\bar q_p T^A u_r)\widetilde H\widetilde G^A_{\mu\nu}B^{\mu\nu}$
$Q^{(3)}_{quGBH}$	$(\bar q_p\sigma^{\mu\nu}T^A u_r)\widetilde HG^A_{\mu\rho}B_{\nu}{}^{\rho}$
$Q^{(1)}_{quW^2H}$	$(\bar q_p u_r)\widetilde HW^I_{\mu\nu}W^{I\mu\nu}$
$Q^{(2)}_{quW^2H}$	$(\bar q_p u_r)\widetilde H\widetilde W^I_{\mu\nu}W^{I\mu\nu}$
$Q^{(3)}_{quW^2H}$	$\epsilon^{IJK}(\bar q_p\sigma^{\mu\nu}u_r)\tau^I\widetilde HW^J_{\mu\rho}W^{K\rho}_{\nu}$
$Q^{(3)}_{quWBH}$	$(\bar q_p\sigma^{\mu\nu}u_r)\tau^I\widetilde HW^I_{\mu\rho}B_{\nu}{}^{\rho}$
$Q^{(1)}_{quWBH}$	$(\bar q_p u_r)\tau^I\widetilde HW^I_{\mu\nu}B^{\mu\nu}$
$Q^{(2)}_{quWBH}$	$(\bar q_p u_r)\tau^I\widetilde H\widetilde W^I_{\mu\nu}B^{\mu\nu}$
$Q^{(1)}_{quB^2H}$	$(\bar q_p u_r)\widetilde HB_{\mu\nu}B^{\mu\nu}$
$Q^{(2)}_{quB^2H}$	$(\bar q_p u_r)\widetilde H\widetilde B_{\mu\nu}B^{\mu\nu}$

$9:\psi^2X^2H+\text{h.c.}$	
$Q^{(1)}_{leWBH}$	$(\bar l_p e_r)\tau^I HW^I_{\mu\nu}B^{\mu\nu}$
$Q^{(2)}_{leWBH}$	$(\bar l_p e_r)\tau^I H\widetilde W^I_{\mu\nu}B^{\mu\nu}$
$Q^{(3)}_{leWBH}$	$(\bar l_p\sigma^{\mu\nu}e_r)\tau^I HW^I_{\mu\rho}B_{\nu}{}^{\rho}$
$Q^{(1)}_{leB^2H}$	$(\bar l_p e_r)HB_{\mu\nu}B^{\mu\nu}$
$Q^{(2)}_{leB^2H}$	$(\bar l_p e_r)H\widetilde B_{\mu\nu}B^{\mu\nu}$
$Q^{(1)}_{qdG^2H}$	$(\bar q_p d_r)HG^A_{\mu\nu}G^{A\mu\nu}$
$Q^{(2)}_{qdG^2H}$	$(\bar q_p d_r)H\widetilde G^A_{\mu\nu}G^{A\mu\nu}$
$Q^{(3)}_{qdG^2H}$	$d^{ABC}(\bar q_p T^A d_r)HG^B_{\mu\nu}G^{C\mu\nu}$
$Q^{(4)}_{qdG^2H}$	$d^{ABC}(\bar q_p T^A d_r)H\widetilde G^B_{\mu\nu}G^{C\mu\nu}$
$Q^{(5)}_{qdG^2H}$	$f^{ABC}(\bar q_p\sigma^{\mu\nu}T^A d_r)HG^B_{\mu\rho}G^{C\rho}_{\nu}$
$Q^{(1)}_{qdGWH}$	$(\bar q_p T^A d_r)\tau^I HG^A_{\mu\nu}W^{I\mu\nu}$
$Q^{(2)}_{qdGWH}$	$(\bar q_p T^A d_r)\tau^I H\widetilde G^A_{\mu\nu}W^{I\mu\nu}$
$Q^{(3)}_{qdGWH}$	$(\bar q_p\sigma^{\mu\nu}T^A d_r)\tau^I HG^A_{\mu\rho}W^{I\rho}_{\nu}$
$Q^{(1)}_{qdGBH}$	$(\bar q_p T^A d_r)HG^A_{\mu\nu}B^{\mu\nu}$
$Q^{(2)}_{qdGBH}$	$(\bar q_p T^A d_r)H\widetilde G^A_{\mu\nu}B^{\mu\nu}$
$Q^{(3)}_{qdGBH}$	$(\bar q_p\sigma^{\mu\nu}T^A d_r)HG^A_{\mu\rho}B_{\nu}{}^{\rho}$
$Q^{(1)}_{qdW^2H}$	$(\bar q_p d_r)HW^I_{\mu\nu}W^{I\mu\nu}$
$Q^{(2)}_{qdW^2H}$	$(\bar q_p d_r)H\widetilde W^I_{\mu\nu}W^{I\mu\nu}$
$Q^{(3)}_{qdW^2H}$	$\epsilon^{IJK}(\bar q_p\sigma^{\mu\nu}d_r)\tau^I HW^J_{\mu\rho}W^{K\rho}_{\nu}$
$Q^{(1)}_{qdWBH}$	$(\bar q_p d_r)\tau^I HW^I_{\mu\nu}B^{\mu\nu}$
$Q^{(2)}_{qdWBH}$	$(\bar q_p d_r)\tau^I H\widetilde W^I_{\mu\nu}B^{\mu\nu}$
$Q^{(3)}_{qdWBH}$	$(\bar q_p\sigma^{\mu\nu}d_r)\tau^I HW^I_{\mu\rho}B_{\nu}{}^{\rho}$
$Q^{(1)}_{qdB^2H}$	$(\bar q_p d_r)HB_{\mu\nu}B^{\mu\nu}$
$Q^{(2)}_{qdB^2H}$	$(\bar q_p d_r)H\widetilde B_{\mu\nu}B^{\mu\nu}$

$10:\psi^2XH^3+\text{h.c.}$	
$Q^{(1)}_{leWH^3}$	$(\bar l_p\sigma^{\mu\nu}e_r)\tau^I H(H^\dagger H)W^I_{\mu\nu}$
$Q^{(2)}_{leWH^3}$	$(\bar l_p\sigma^{\mu\nu}e_r)H(H^\dagger\tau^I H)W^I_{\mu\nu}$
Q_{leBH^3}	$(\bar l_p\sigma^{\mu\nu}e_r)H(H^\dagger H)B_{\mu\nu}$
Q_{quGH^3}	$(\bar q_p\sigma^{\mu\nu}T^A u_r)\widetilde H(H^\dagger H)G^A_{\mu\nu}$
$Q^{(1)}_{quWH^3}$	$(\bar q_p\sigma^{\mu\nu}u_r)\tau^I\widetilde H(H^\dagger H)W^I_{\mu\nu}$
$Q^{(2)}_{quWH^3}$	$(\bar q_p\sigma^{\mu\nu}u_r)\widetilde H(H^\dagger\tau^I H)W^I_{\mu\nu}$
Q_{quBH^3}	$(\bar q_p\sigma^{\mu\nu}u_r)\widetilde H(H^\dagger H)B_{\mu\nu}$
Q_{qdGH^3}	$(\bar q_p\sigma^{\mu\nu}T^A d_r)H(H^\dagger H)G^A_{\mu\nu}$
$Q^{(1)}_{qdWH^3}$	$(\bar q_p\sigma^{\mu\nu}d_r)\tau^I H(H^\dagger H)W^I_{\mu\nu}$
$Q^{(2)}_{qdWH^3}$	$(\bar q_p\sigma^{\mu\nu}d_r)H(H^\dagger\tau^I H)W^I_{\mu\nu}$
Q_{qdBH^3}	$(\bar q_p\sigma^{\mu\nu}d_r)H(H^\dagger H)B_{\mu\nu}$

$11:\psi^2H^2D^3$	
$Q^{(1)}_{l^2H^2D^3}$	$i(\bar l_p\gamma^\mu D^\nu l_r)(D_{(\mu}D_{\nu)}H^\dagger H)$
$Q^{(2)}_{l^2H^2D^3}$	$i(\bar l_p\gamma^\mu D^\nu l_r)(H^\dagger D_{(\mu}D_{\nu)}H)$
$Q^{(3)}_{l^2H^2D^3}$	$i(\bar l_p\gamma^\mu\tau^I D^\nu l_r)(D_{(\mu}D_{\nu)}H^\dagger\tau^I H)$
$Q^{(4)}_{l^2H^2D^3}$	$i(\bar l_p\gamma^\mu\tau^I D^\nu l_r)(H^\dagger\tau^I D_{(\mu}D_{\nu)}H)$
$Q^{(1)}_{e^2H^2D^3}$	$i(\bar e_p\gamma^\mu D^\nu e_r)(D_{(\mu}D_{\nu)}H^\dagger H)$
$Q^{(2)}_{e^2H^2D^3}$	$i(\bar e_p\gamma^\mu D^\nu e_r)(H^\dagger D_{(\mu}D_{\nu)}H)$
$Q^{(1)}_{q^2H^2D^3}$	$i(\bar q_p\gamma^\mu D^\nu q_r)(D_{(\mu}D_{\nu)}H^\dagger H)$
$Q^{(2)}_{q^2H^2D^3}$	$i(\bar q_p\gamma^\mu D^\nu q_r)(H^\dagger D_{(\mu}D_{\nu)}H)$
$Q^{(3)}_{q^2H^2D^3}$	$i(\bar q_p\gamma^\mu\tau^I D^\nu q_r)(D_{(\mu}D_{\nu)}H^\dagger\tau^I H)$
$Q^{(4)}_{q^2H^2D^2}$	$i(\bar q_p\gamma^\mu\tau^I D^\nu q_r)(H^\dagger\tau^I D_{(\mu}D_{\nu)}H)$
$Q^{(1)}_{u^2H^2D^3}$	$i(\bar u_p\gamma^\mu D^\nu u_r)(D_{(\mu}D_{\nu)}H^\dagger H)$
$Q^{(2)}_{u^2H^2D^3}$	$i(\bar u_p\gamma^\mu D^\nu u_r)(H^\dagger D_{(\mu}D_{\nu)}H)$
$Q^{(1)}_{d^2H^2D^3}$	$i(\bar d_p\gamma^\mu D^\nu d_r)(D_{(\mu}D_{\nu)}H^\dagger H)$
$Q^{(2)}_{d^2H^2D^3}$	$i(\bar d_p\gamma^\mu D^\nu d_r)(H^\dagger D_{(\mu}D_{\nu)}H)$
$Q_{udH^2D^3}+\text{h.c.}$	$i(\bar u_p\gamma^\mu D^\nu d_r)(\widetilde H^\dagger D_{(\mu}D_{\nu)}H)$

$12:\psi^2H^5+\text{h.c.}$	
Q_{leH^5}	$(H^\dagger H)^2(\bar l_p e_r H)$
Q_{quH^5}	$(H^\dagger H)^2(\bar q_p u_r\widetilde H)$
Q_{qdH^5}	$(H^\dagger H)^2(\bar q_p d_r H)$

$13:\psi^2H^4D$	
$Q^{(1)}_{l^2H^4D}$	$i(l_p\gamma^\mu l_r)(H^\dagger\overleftrightarrow{D}_\mu H)(H^\dagger H)$
$Q^{(2)}_{l^2H^4D}$	$i(l_p\gamma^\mu\tau^I l_r)[(H^\dagger\overleftrightarrow{D}^I_\mu H)(H^\dagger H)+(H^\dagger\overleftrightarrow{D}_\mu H)(H^\dagger\tau^I H)]$
$Q^{(3)}_{l^2H^4D}$	$i\epsilon^{IJK}(l_p\gamma^\mu\tau^I l_r)(H^\dagger\overleftrightarrow{D}^J_\mu H)(H^\dagger\tau^K H)$
$Q^{(4)}_{l^2H^4D}$	$\epsilon^{IJK}(l_p\gamma^\mu\tau^I l_r)(H^\dagger\tau^J H)D_\mu(H^\dagger\tau^K H)$
$Q_{e^2H^4D}$	$i(e_p\gamma^\mu e_r)(H^\dagger\overleftrightarrow{D}_\mu H)(H^\dagger H)$
$Q^{(1)}_{q^2H^4D}$	$i(q_p\gamma^\mu q_r)(H^\dagger\overleftrightarrow{D}_\mu H)(H^\dagger H)$
$Q^{(2)}_{q^2H^4D}$	$i(q_p\gamma^\mu\tau^I q_r)[(H^\dagger\overleftrightarrow{D}^I_\mu H)(H^\dagger H)+(H^\dagger\overleftrightarrow{D}_\mu H)(H^\dagger\tau^I H)]$
$Q^{(3)}_{q^2H^4D}$	$i\epsilon^{IJK}(q_p\gamma^\mu\tau^I q_r)(H^\dagger\overleftrightarrow{D}^J_\mu H)(H^\dagger\tau^K H)$
$Q^{(4)}_{q^2H^4D}$	$\epsilon^{IJK}(q_p\gamma^\mu\tau^I q_r)(H^\dagger\tau^J H)D_\mu(H^\dagger\tau^K H)$
$Q_{u^2H^4D}$	$i(u_p\gamma^\mu u_r)(H^\dagger\overleftrightarrow{D}_\mu H)(H^\dagger H)$
$Q_{d^2H^4D}$	$i(d_p\gamma^\mu d_r)(H^\dagger\overleftrightarrow{D}_\mu H)(H^\dagger H)$
$Q_{udH^4D}+\text{h.c.}$	$i(u_p\gamma^\mu d_r)(\widetilde H^\dagger\overleftrightarrow{D}_\mu H)(H^\dagger H)$

SMEFT at $d = 8$: Murphy basis

Murphy 2206.07722
see also: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008

14 : $\psi^2 X^2 D$	
$Q^{(1)}_{q^2G^2D}$	$i(\bar q_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)G^A_{\mu\rho}G^{A\rho}_\nu$
$Q^{(2)}_{q^2G^2D}$	$f^{ABC}(\bar q_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)G^B_{\mu\rho}G^{C\rho}_\nu$
$Q^{(3)}_{q^2G^2D}$	$id^{ABC}(\bar q_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)G^B_{\mu\rho}G^{C\rho}_\nu$
$Q^{(1)}_{q^2W^2D}$	$i(\bar q_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)W^I_{\mu\rho}W^{I\rho}_\nu$
$Q^{(2)}_{q^2W^2D}$	$\epsilon^{IJK}(\bar q_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu q_r)W^J_{\mu\rho}W^{K\rho}_\nu$
$Q_{q^2B^2D}$	$i(\bar q_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)B_{\mu\rho}B_\nu{}^\rho$
$Q^{(1)}_{u^2G^2D}$	$i(\bar u_p\gamma^\mu \overleftrightarrow{D}^\nu u_r)G^A_{\mu\rho}G^{A\rho}_\nu$
$Q^{(2)}_{u^2G^2D}$	$f^{ABC}(\bar u_p\gamma^\mu T^A \overleftrightarrow{D}^\nu u_r)G^B_{\mu\rho}G^{C\rho}_\nu$
$Q^{(3)}_{u^2G^2D}$	$id^{ABC}(\bar u_p\gamma^\mu T^A \overleftrightarrow{D}^\nu u_r)G^B_{\mu\rho}G^{C\rho}_\nu$
$Q_{u^2W^2D}$	$i(\bar u_p\gamma^\mu \overleftrightarrow{D}^\nu u_r)W^I_{\mu\rho}W^{I\rho}_\nu$
$Q_{u^2B^2D}$	$i(\bar u_p\gamma^\mu \overleftrightarrow{D}^\nu u_r)B_{\mu\rho}B_\nu{}^\rho$
$Q^{(1)}_{d^2G^2D}$	$i(\bar d_p\gamma^\mu \overleftrightarrow{D}^\nu d_r)G^A_{\mu\rho}G^{A\rho}_\nu$
$Q^{(2)}_{d^2G^2D}$	$f^{ABC}(\bar d_p\gamma^\mu T^A \overleftrightarrow{D}^\nu d_r)G^B_{\mu\rho}G^{C\rho}_\nu$
$Q^{(3)}_{d^2G^2D}$	$id^{ABC}(\bar d_p\gamma^\mu T^A \overleftrightarrow{D}^\nu d_r)G^B_{\mu\rho}G^{C\rho}_\nu$
$Q_{d^2W^2D}$	$i(\bar d_p\gamma^\mu \overleftrightarrow{D}^\nu d_r)W^I_{\mu\rho}W^{I\rho}_\nu$
$Q_{d^2B^2D}$	$i(\bar d_p\gamma^\mu \overleftrightarrow{D}^\nu d_r)B_{\mu\rho}B_\nu{}^\rho$

14 : $\psi^2 X^2 D$	
$Q^{(4)}_{q^2G^2D}$	$if^{ABC}(\bar q_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)(G^B_{\mu\rho}\widetilde G^{C\rho}_\nu - \widetilde G^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(5)}_{q^2G^2D}$	$f^{ABC}(\bar q_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)(G^B_{\mu\rho}\widetilde G^{C\rho}_\nu + \widetilde G^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(1)}_{q^2GWD}$	$(\bar q_p\gamma^\mu T^A\tau^I \overleftrightarrow{D}^\nu q_r)(G^A_{\mu\rho}W^{I\rho}_\nu - G^A_{\nu\rho}W^{I\rho}_\mu)$
$Q^{(2)}_{q^2GWD}$	$i(\bar q_p\gamma^\mu T^A\tau^I \overleftrightarrow{D}^\nu q_r)(G^A_{\mu\rho}W^{I\rho}_\nu + G^A_{\nu\rho}W^{I\rho}_\mu)$
$Q^{(3)}_{q^2GWD}$	$(\bar q_p\gamma^\mu T^A\tau^I \overleftrightarrow{D}^\nu q_r)(G^A_{\mu\rho}\widetilde W^{I\rho}_\nu - G^A_{\nu\rho}\widetilde W^{I\rho}_\mu)$
$Q^{(4)}_{q^2GWD}$	$i(\bar q_p\gamma^\mu T^A\tau^I \overleftrightarrow{D}^\nu q_r)(G^A_{\mu\rho}\widetilde W^{I\rho}_\nu + G^A_{\nu\rho}\widetilde W^{I\rho}_\mu)$
$Q^{(1)}_{q^2GBD}$	$(\bar q_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}G^{A\rho}_\nu - B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(2)}_{q^2GBD}$	$i(\bar q_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}G^{A\rho}_\nu + B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(3)}_{q^2GBD}$	$(\bar q_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}\widetilde G^{A\rho}_\nu - B_{\nu\rho}\widetilde G^{A\rho}_\mu)$
$Q^{(4)}_{q^2GBD}$	$i(\bar q_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}\widetilde G^{A\rho}_\nu + B_{\nu\rho}\widetilde G^{A\rho}_\mu)$
$Q^{(3)}_{q^2W^2D}$	$i\epsilon^{IJK}(\bar q_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu q_r)(W^J_{\mu\rho}\widetilde W^{K\rho}_\nu - \widetilde W^J_{\mu\rho}W^{K\rho}_\nu)$
$Q^{(4)}_{q^2W^2D}$	$\epsilon^{IJK}(\bar q_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu q_r)(W^J_{\mu\rho}\widetilde W^{K\rho}_\nu + \widetilde W^J_{\mu\rho}W^{K\rho}_\nu)$
$Q^{(1)}_{q^2WBD}$	$(\bar q_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}W^{I\rho}_\nu - B_{\nu\rho}W^{I\rho}_\mu)$
$Q^{(2)}_{q^2WBD}$	$i(\bar q_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}W^{I\rho}_\nu + B_{\nu\rho}W^{I\rho}_\mu)$
$Q^{(3)}_{q^2WBD}$	$(\bar q_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}\widetilde W^{I\rho}_\nu - B_{\nu\rho}\widetilde W^{I\rho}_\mu)$
$Q^{(4)}_{q^2WBD}$	$i(\bar q_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}\widetilde W^{I\rho}_\nu + B_{\nu\rho}\widetilde W^{I\rho}_\mu)$
$Q^{(4)}_{u^2G^2D}$	$if^{ABC}(\bar u_p\gamma^\mu T^A \overleftrightarrow{D}^\nu u_r)(G^B_{\mu\rho}\widetilde G^{C\rho}_\nu - \widetilde G^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(5)}_{u^2G^2D}$	$f^{ABC}(\bar u_p\gamma^\mu T^A \overleftrightarrow{D}^\nu u_r)(G^B_{\mu\rho}\widetilde G^{C\rho}_\nu + \widetilde G^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(1)}_{u^2GBD}$	$(\bar u_p\gamma^\mu T^A \overleftrightarrow{D}^\nu u_r)(B_{\mu\rho}G^{A\rho}_\nu - B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(2)}_{u^2GBD}$	$i(\bar u_p\gamma^\mu T^A \overleftrightarrow{D}^\nu u_r)(B_{\mu\rho}G^{A\rho}_\nu + B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(3)}_{u^2GBD}$	$(\bar u_p\gamma^\mu T^A \overleftrightarrow{D}^\nu u_r)(B_{\mu\rho}\widetilde G^{A\rho}_\nu - B_{\nu\rho}\widetilde G^{A\rho}_\mu)$
$Q^{(4)}_{u^2GBD}$	$i(\bar u_p\gamma^\mu T^A \overleftrightarrow{D}^\nu u_r)(B_{\mu\rho}\widetilde G^{A\rho}_\nu + B_{\nu\rho}\widetilde G^{A\rho}_\mu)$
$Q^{(4)}_{d^2G^2D}$	$if^{ABC}(\bar d_p\gamma^\mu T^A \overleftrightarrow{D}^\nu d_r)(G^B_{\mu\rho}\widetilde G^{C\rho}_\nu - \widetilde G^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(5)}_{d^2G^2D}$	$f^{ABC}(\bar d_p\gamma^\mu T^A \overleftrightarrow{D}^\nu d_r)(G^B_{\mu\rho}\widetilde G^{C\rho}_\nu + \widetilde G^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(1)}_{d^2GBD}$	$(\bar d_p\gamma^\mu T^A \overleftrightarrow{D}^\nu d_r)(B_{\mu\rho}G^{A\rho}_\nu - B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(2)}_{d^2GBD}$	$i(\bar d_p\gamma^\mu T^A \overleftrightarrow{D}^\nu d_r)(B_{\mu\rho}G^{A\rho}_\nu + B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(3)}_{d^2GBD}$	$(\bar d_p\gamma^\mu T^A \overleftrightarrow{D}^\nu d_r)(B_{\mu\rho}\widetilde G^{A\rho}_\nu - B_{\nu\rho}\widetilde G^{A\rho}_\mu)$
$Q^{(4)}_{d^2GBD}$	$i(\bar d_p\gamma^\mu T^A \overleftrightarrow{D}^\nu d_r)(B_{\mu\rho}\widetilde G^{A\rho}_\nu + B_{\nu\rho}\widetilde G^{A\rho}_\mu)$

14 : $\psi^2 X^2 D$	
$Q_{l^2G^2D}$	$i(\bar l_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)G^A_{\mu\rho}G^{A\rho}_\nu$
$Q^{(1)}_{l^2W^2D}$	$i(\bar l_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)W^I_{\mu\rho}W^{I\rho}_\nu$
$Q^{(2)}_{l^2W^2D}$	$\epsilon^{IJK}(\bar l_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu l_r)W^J_{\mu\rho}W^{K\rho}_\nu$
$Q_{l^2B^2D}$	$i(\bar l_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)B_{\mu\rho}B_\nu{}^\rho$
$Q_{e^2G^2D}$	$i(\bar e_p\gamma^\mu \overleftrightarrow{D}^\nu e_r)G^A_{\mu\rho}G^{A\rho}_\nu$
$Q_{e^2W^2D}$	$i(\bar e_p\gamma^\mu \overleftrightarrow{D}^\nu e_r)W^I_{\mu\rho}W^{I\rho}_\nu$
$Q_{e^2B^2D}$	$i(\bar e_p\gamma^\mu \overleftrightarrow{D}^\nu e_r)B_{\mu\rho}B_\nu{}^\rho$

14 : $\psi^2 X^2 D$	
$Q^{(3)}_{l^2W^2D}$	$i\epsilon^{IJK}(\bar l_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu l_r)(W^J_{\mu\rho}\widetilde W^{K\rho}_\nu - \widetilde W^J_{\mu\rho}W^{K\rho}_\nu)$
$Q^{(4)}_{l^2W^2D}$	$\epsilon^{IJK}(\bar l_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu l_r)(W^J_{\mu\rho}\widetilde W^{K\rho}_\nu + \widetilde W^J_{\mu\rho}W^{K\rho}_\nu)$
$Q^{(1)}_{l^2WBD}$	$(\bar l_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu l_r)(B_{\mu\rho}W^{I\rho}_\nu - B_{\nu\rho}W^{I\rho}_\mu)$
$Q^{(2)}_{l^2WBD}$	$i(\bar l_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu l_r)(B_{\mu\rho}W^{I\rho}_\nu + B_{\nu\rho}W^{I\rho}_\mu)$
$Q^{(3)}_{l^2WBD}$	$(\bar l_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu l_r)(B_{\mu\rho}\widetilde W^{I\rho}_\nu - B_{\nu\rho}\widetilde W^{I\rho}_\mu)$
$Q^{(4)}_{l^2WBD}$	$i(\bar l_p\gamma^\mu \tau^I \overleftrightarrow{D}^\nu l_r)(B_{\mu\rho}\widetilde W^{I\rho}_\nu + B_{\nu\rho}\widetilde W^{I\rho}_\mu)$

15 : $(\bar R R) X H^2 D$	
$Q^{(1)}_{e^2WH^2D}$	$(\bar e_p\gamma^\nu e_r)D^\mu(H^\dagger\tau^I H)W^I_{\mu\nu}$
$Q^{(2)}_{e^2WH^2D}$	$(\bar e_p\gamma^\nu e_r)D^\mu(H^\dagger\tau^I H)\widetilde W^I_{\mu\nu}$
$Q^{(3)}_{e^2WH^2D}$	$(\bar e_p\gamma^\nu e_r)(H^\dagger \overleftrightarrow{D}^{I\mu} H)W^I_{\mu\nu}$
$Q^{(4)}_{e^2WH^2D}$	$(\bar e_p\gamma^\nu e_r)(H^\dagger \overleftrightarrow{D}^{I\mu} H)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{e^2BH^2D}$	$(\bar e_p\gamma^\nu e_r)D^\mu(H^\dagger H)B_{\mu\nu}$
$Q^{(2)}_{e^2BH^2D}$	$(\bar e_p\gamma^\nu e_r)D^\mu(H^\dagger H)\widetilde B_{\mu\nu}$
$Q^{(3)}_{e^2BH^2D}$	$(\bar e_p\gamma^\nu e_r)(H^\dagger \overleftrightarrow{D}^\mu H)B_{\mu\nu}$
$Q^{(4)}_{e^2BH^2D}$	$(\bar e_p\gamma^\nu e_r)(H^\dagger \overleftrightarrow{D}^\mu H)\widetilde B_{\mu\nu}$
$Q^{(1)}_{u^2GH^2D}$	$(\bar u_p\gamma^\nu T^A u_r)D^\mu(H^\dagger H)G^A_{\mu\nu}$
$Q^{(2)}_{u^2GH^2D}$	$(\bar u_p\gamma^\nu T^A u_r)D^\mu(H^\dagger H)\widetilde G^A_{\mu\nu}$
$Q^{(3)}_{u^2GH^2D}$	$(\bar u_p\gamma^\nu T^A u_r)(H^\dagger \overleftrightarrow{D}^\mu H)G^A_{\mu\nu}$
$Q^{(4)}_{u^2GH^2D}$	$(\bar u_p\gamma^\nu T^A u_r)(H^\dagger \overleftrightarrow{D}^\mu H)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{u^2WH^2D}$	$(\bar u_p\gamma^\nu u_r)D^\mu(H^\dagger\tau^I H)W^I_{\mu\nu}$
$Q^{(2)}_{u^2WH^2D}$	$(\bar u_p\gamma^\nu u_r)D^\mu(H^\dagger\tau^I H)\widetilde W^I_{\mu\nu}$
$Q^{(3)}_{u^2WH^2D}$	$(\bar u_p\gamma^\nu u_r)(H^\dagger \overleftrightarrow{D}^{I\mu} H)W^I_{\mu\nu}$
$Q^{(4)}_{u^2WH^2D}$	$(\bar u_p\gamma^\nu u_r)(H^\dagger \overleftrightarrow{D}^{I\mu} H)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{u^2BH^2D}$	$(\bar u_p\gamma^\nu u_r)D^\mu(H^\dagger H)B_{\mu\nu}$
$Q^{(2)}_{u^2BH^2D}$	$(\bar u_p\gamma^\nu u_r)D^\mu(H^\dagger H)\widetilde B_{\mu\nu}$
$Q^{(3)}_{u^2BH^2D}$	$(\bar u_p\gamma^\nu u_r)(H^\dagger \overleftrightarrow{D}^\mu H)B_{\mu\nu}$
$Q^{(4)}_{u^2BH^2D}$	$(\bar u_p\gamma^\nu u_r)(H^\dagger \overleftrightarrow{D}^\mu H)\widetilde B_{\mu\nu}$

15 : $(\bar R R) X H^2 D$	
$Q^{(1)}_{d^2GH^2D}$	$(\bar d_p\gamma^\nu T^A d_r)D^\mu(H^\dagger H)G^A_{\mu\nu}$
$Q^{(2)}_{d^2GH^2D}$	$(\bar d_p\gamma^\nu T^A d_r)D^\mu(H^\dagger H)\widetilde G^A_{\mu\nu}$
$Q^{(3)}_{d^2GH^2D}$	$(\bar d_p\gamma^\nu T^A d_r)(H^\dagger \overleftrightarrow{D}^\mu H)G^A_{\mu\nu}$
$Q^{(4)}_{d^2GH^2D}$	$(\bar d_p\gamma^\nu T^A d_r)(H^\dagger \overleftrightarrow{D}^\mu H)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{d^2WH^2D}$	$(\bar d_p\gamma^\nu d_r)D^\mu(H^\dagger\tau^I H)W^I_{\mu\nu}$
$Q^{(2)}_{d^2WH^2D}$	$(\bar d_p\gamma^\nu d_r)D^\mu(H^\dagger\tau^I H)\widetilde W^I_{\mu\nu}$
$Q^{(3)}_{d^2WH^2D}$	$(\bar d_p\gamma^\nu d_r)(H^\dagger \overleftrightarrow{D}^{I\mu} H)W^I_{\mu\nu}$
$Q^{(4)}_{d^2WH^2D}$	$(\bar d_p\gamma^\nu d_r)(H^\dagger \overleftrightarrow{D}^{I\mu} H)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{d^2BH^2D}$	$(\bar d_p\gamma^\nu d_r)D^\mu(H^\dagger H)B_{\mu\nu}$
$Q^{(2)}_{d^2BH^2D}$	$(\bar d_p\gamma^\nu d_r)D^\mu(H^\dagger H)\widetilde B_{\mu\nu}$
$Q^{(3)}_{d^2BH^2D}$	$(\bar d_p\gamma^\nu d_r)(H^\dagger \overleftrightarrow{D}^\mu H)B_{\mu\nu}$
$Q^{(4)}_{d^2BH^2D}$	$(\bar d_p\gamma^\nu d_r)(H^\dagger \overleftrightarrow{D}^\mu H)\widetilde B_{\mu\nu}$
$Q^{(1)}_{udGH^2}$ + h.c.	$(\bar u_p\gamma^\nu T^A d_r)(\widetilde H^\dagger \overleftrightarrow{D}^\mu H)G^A_{\mu\nu}$
$Q^{(2)}_{udGH^2}$ + h.c.	$(\bar u_p\gamma^\nu T^A d_r)(\widetilde H^\dagger \overleftrightarrow{D}^\mu H)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{udWH^2}$ + h.c.	$(\bar u_p\gamma^\nu d_r)(\widetilde H^\dagger \overleftrightarrow{D}^{I\mu} H)W^I_{\mu\nu}$
$Q^{(2)}_{udWH^2}$ + h.c.	$(\bar u_p\gamma^\nu d_r)(\widetilde H^\dagger \overleftrightarrow{D}^{I\mu} H)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{udBH^2}$ + h.c.	$(\bar u_p\gamma^\nu d_r)(\widetilde H^\dagger \overleftrightarrow{D}^\mu H)B_{\mu\nu}$
$Q^{(2)}_{udBH^2}$ + h.c.	$(\bar u_p\gamma^\nu d_r)(\widetilde H^\dagger \overleftrightarrow{D}^\mu H)\widetilde B_{\mu\nu}$

SMEFT at $d = 8$: Murphy basis

Murphy 2206.07722
see also: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008

15 : $(\bar L L) X H^2 D$

$Q^{(1)}_{l^2WH^2D}$	$(\bar l_p\gamma^\nu l_r)D^\mu(H^\dagger\tau^I H)W^I_{\mu\nu}$
$Q^{(2)}_{l^2WH^2D}$	$(\bar l_p\gamma^\nu l_r)D^\mu(H^\dagger\tau^I H)\widetilde W^I_{\mu\nu}$
$Q^{(3)}_{l^2WH^2D}$	$(\bar l_p\gamma^\nu l_r)(H^\dagger\overleftrightarrow{D}^{I\mu}H)W^I_{\mu\nu}$
$Q^{(4)}_{l^2WH^2D}$	$(\bar l_p\gamma^\nu l_r)(H^\dagger\overleftrightarrow{D}^{I\mu}H)\widetilde W^I_{\mu\nu}$
$Q^{(5)}_{l^2WH^2D}$	$(\bar l_p\gamma^\nu\tau^I l_r)D^\mu(H^\dagger H)W^I_{\mu\nu}$
$Q^{(6)}_{l^2WH^2D}$	$(\bar l_p\gamma^\nu\tau^I l_r)D^\mu(H^\dagger H)\widetilde W^I_{\mu\nu}$
$Q^{(7)}_{l^2WH^2D}$	$(\bar l_p\gamma^\nu\tau^I l_r)(H^\dagger\overleftrightarrow{D}^{\mu}H)W^I_{\mu\nu}$
$Q^{(8)}_{l^2WH^2D}$	$(\bar l_p\gamma^\nu\tau^I l_r)(H^\dagger\overleftrightarrow{D}^{\mu}H)\widetilde W^I_{\mu\nu}$
$Q^{(9)}_{l^2WH^2D}$	$\epsilon^{IJK}(\bar l_p\gamma^\nu\tau^I l_r)D^\mu(H^\dagger\tau^J H)W^K_{\mu\nu}$
$Q^{(10)}_{l^2WH^2D}$	$\epsilon^{IJK}(\bar l_p\gamma^\nu\tau^I l_r)D^\mu(H^\dagger\tau^J H)\widetilde W^K_{\mu\nu}$
$Q^{(11)}_{l^2WH^2D}$	$\epsilon^{IJK}(\bar l_p\gamma^\nu\tau^I l_r)(H^\dagger\overleftrightarrow{D}^{J\mu}H)W^K_{\mu\nu}$
$Q^{(12)}_{l^2WH^2D}$	$\epsilon^{IJK}(\bar l_p\gamma^\nu\tau^I l_r)(H^\dagger\overleftrightarrow{D}^{J\mu}H)\widetilde W^K_{\mu\nu}$
$Q^{(1)}_{l^2BH^2D}$	$(\bar l_p\gamma^\nu\tau^I l_r)D^\mu(H^\dagger\tau^I H)B_{\mu\nu}$
$Q^{(2)}_{l^2BH^2D}$	$(\bar l_p\gamma^\nu\tau^I l_r)D^\mu(H^\dagger\tau^I H)\widetilde B_{\mu\nu}$
$Q^{(3)}_{l^2BH^2D}$	$(\bar l_p\gamma^\nu\tau^I l_r)(H^\dagger\overleftrightarrow{D}^{I\mu}H)B_{\mu\nu}$
$Q^{(4)}_{l^2BH^2D}$	$(\bar l_p\gamma^\nu\tau^I l_r)(H^\dagger\overleftrightarrow{D}^{I\mu}H)\widetilde B_{\mu\nu}$
$Q^{(5)}_{l^2BH^2D}$	$(\bar l_p\gamma^\nu l_r)D^\mu(H^\dagger H)B_{\mu\nu}$
$Q^{(6)}_{l^2BH^2D}$	$(\bar l_p\gamma^\nu l_r)D^\mu(H^\dagger H)\widetilde B_{\mu\nu}$
$Q^{(7)}_{l^2BH^2D}$	$(\bar l_p\gamma^\nu l_r)(H^\dagger\overleftrightarrow{D}^{\mu}H)B_{\mu\nu}$
$Q^{(8)}_{l^2BH^2D}$	$(\bar l_p\gamma^\nu l_r)(H^\dagger\overleftrightarrow{D}^{\mu}H)\widetilde B_{\mu\nu}$

15 : $(\bar L L) X H^2 D$

$Q^{(1)}_{q^2GH^2D}$	$(\bar q_p\gamma^\nu T^A\tau^I q_r)D^\mu(H^\dagger\tau^I H)G^A_{\mu\nu}$
$Q^{(2)}_{q^2GH^2D}$	$(\bar q_p\gamma^\nu T^A\tau^I q_r)D^\mu(H^\dagger\tau^I H)\widetilde G^A_{\mu\nu}$
$Q^{(3)}_{q^2GH^2D}$	$(\bar q_p\gamma^\nu T^A\tau^I q_r)(H^\dagger\overleftrightarrow{D}^{I\mu}H)G^A_{\mu\nu}$
$Q^{(4)}_{q^2GH^2D}$	$(\bar q_p\gamma^\nu T^A\tau^I q_r)(H^\dagger\overleftrightarrow{D}^{I\mu}H)\widetilde G^A_{\mu\nu}$
$Q^{(5)}_{q^2GH^2D}$	$(\bar q_p\gamma^\nu T^A q_r)D^\mu(H^\dagger H)G^A_{\mu\nu}$
$Q^{(6)}_{q^2GH^2D}$	$(\bar q_p\gamma^\nu T^A q_r)D^\mu(H^\dagger H)\widetilde G^A_{\mu\nu}$
$Q^{(7)}_{q^2GH^2D}$	$(\bar q_p\gamma^\nu T^A q_r)(H^\dagger\overleftrightarrow{D}^{\mu}H)G^A_{\mu\nu}$
$Q^{(8)}_{q^2GH^2D}$	$(\bar q_p\gamma^\nu T^A q_r)(H^\dagger\overleftrightarrow{D}^{\mu}H)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{q^2WH^2D}$	$(\bar q_p\gamma^\nu q_r)D^\mu(H^\dagger\tau^I H)W^I_{\mu\nu}$
$Q^{(2)}_{q^2WH^2D}$	$(\bar q_p\gamma^\nu q_r)D^\mu(H^\dagger\tau^I H)\widetilde W^I_{\mu\nu}$
$Q^{(3)}_{q^2WH^2D}$	$(\bar q_p\gamma^\nu q_r)(H^\dagger\overleftrightarrow{D}^{I\mu}H)W^I_{\mu\nu}$
$Q^{(4)}_{q^2WH^2D}$	$(\bar q_p\gamma^\nu q_r)(H^\dagger\overleftrightarrow{D}^{I\mu}H)\widetilde W^I_{\mu\nu}$
$Q^{(5)}_{q^2WH^2D}$	$(\bar q_p\gamma^\nu\tau^I q_r)D^\mu(H^\dagger H)W^I_{\mu\nu}$
$Q^{(6)}_{q^2WH^2D}$	$(\bar q_p\gamma^\nu\tau^I q_r)D^\mu(H^\dagger H)\widetilde W^I_{\mu\nu}$
$Q^{(7)}_{q^2WH^2D}$	$(\bar q_p\gamma^\nu\tau^I q_r)(H^\dagger\overleftrightarrow{D}^{\mu}H)W^I_{\mu\nu}$
$Q^{(8)}_{q^2WH^2D}$	$(\bar q_p\gamma^\nu\tau^I q_r)(H^\dagger\overleftrightarrow{D}^{\mu}H)\widetilde W^I_{\mu\nu}$
$Q^{(9)}_{q^2WH^2D}$	$\epsilon^{IJK}(\bar q_p\gamma^\nu\tau^I q_r)D^\mu(H^\dagger\tau^J H)W^K_{\mu\nu}$
$Q^{(10)}_{q^2WH^2D}$	$\epsilon^{IJK}(\bar q_p\gamma^\nu\tau^I q_r)D^\mu(H^\dagger\tau^J H)\widetilde W^K_{\mu\nu}$
$Q^{(11)}_{q^2WH^2D}$	$\epsilon^{IJK}(\bar q_p\gamma^\nu\tau^I q_r)(H^\dagger\overleftrightarrow{D}^{J\mu}H)W^K_{\mu\nu}$
$Q^{(12)}_{q^2WH^2D}$	$\epsilon^{IJK}(\bar q_p\gamma^\nu\tau^I q_r)(H^\dagger\overleftrightarrow{D}^{J\mu}H)\widetilde W^K_{\mu\nu}$
$Q^{(1)}_{q^2BH^2D}$	$(\bar q_p\gamma^\nu\tau^I q_r)D^\mu(H^\dagger\tau^I H)B_{\mu\nu}$
$Q^{(2)}_{q^2BH^2D}$	$(\bar q_p\gamma^\nu\tau^I q_r)D^\mu(H^\dagger\tau^I H)\widetilde B_{\mu\nu}$
$Q^{(3)}_{q^2BH^2D}$	$(\bar q_p\gamma^\nu\tau^I q_r)(H^\dagger\overleftrightarrow{D}^{I\mu}H)B_{\mu\nu}$
$Q^{(4)}_{q^2BH^2D}$	$(\bar q_p\gamma^\nu\tau^I q_r)(H^\dagger\overleftrightarrow{D}^{I\mu}H)\widetilde B_{\mu\nu}$
$Q^{(5)}_{q^2BH^2D}$	$(\bar q_p\gamma^\nu q_r)D^\mu(H^\dagger H)B_{\mu\nu}$
$Q^{(6)}_{q^2BH^2D}$	$(\bar q_p\gamma^\nu q_r)D^\mu(H^\dagger H)\widetilde B_{\mu\nu}$
$Q^{(7)}_{q^2BH^2D}$	$(\bar q_p\gamma^\nu q_r)(H^\dagger\overleftrightarrow{D}^{\mu}H)B_{\mu\nu}$
$Q^{(8)}_{q^2BH^2D}$	$(\bar q_p\gamma^\nu q_r)(H^\dagger\overleftrightarrow{D}^{\mu}H)\widetilde B_{\mu\nu}$

16 : $\psi^2 X H D^2$ + h.c.

$Q^{(1)}_{leWHD^2}$	$(\bar l_p\sigma^{\mu\nu}D^\rho e_r)\tau^I(D_\nu H)W^I_{\rho\mu}$
$Q^{(2)}_{leWHD^2}$	$(\bar l_p D^\rho e_r)\tau^I(D^\nu H)\widetilde W^I_{\rho\nu}$
$Q^{(3)}_{leWHD^2}$	$(\bar l_p\sigma^{\mu\nu}e_r)\tau^I(D^\rho H)(D_\rho W^I_{\mu\nu})$
$Q^{(1)}_{leBHD^2}$	$(\bar l_p\sigma^{\mu\nu}D^\rho e_r)(D_\nu H)B_{\rho\mu}$
$Q^{(2)}_{leBHD^2}$	$(\bar l_p D^\rho e_r)(D^\nu H)\widetilde B_{\rho\nu}$
$Q^{(3)}_{leBHD^2}$	$(\bar l_p\sigma^{\mu\nu}e_r)(D^\rho H)(D_\rho B_{\mu\nu})$
$Q^{(1)}_{quGHD^2}$	$(\bar q_p\sigma^{\mu\nu}T^A D^\rho u_r)(D_\nu\widetilde H)G^A_{\rho\mu}$
$Q^{(2)}_{quGHD^2}$	$(\bar q_p T^A D^\rho u_r)(D^\nu\widetilde H)\widetilde G^A_{\rho\nu}$
$Q^{(3)}_{quGHD^2}$	$(\bar q_p\sigma^{\mu\nu}T^A u_r)(D^\rho\widetilde H)(D_\rho G^A_{\mu\nu})$
$Q^{(1)}_{quWHD^2}$	$(\bar q_p\sigma^{\mu\nu}D^\rho u_r)\tau^I(D_\nu\widetilde H)W^I_{\rho\mu}$
$Q^{(2)}_{quWHD^2}$	$(\bar q_p D^\rho u_r)\tau^I(D^\nu\widetilde H)\widetilde W^I_{\rho\nu}$
$Q^{(3)}_{quWHD^2}$	$(\bar q_p\sigma^{\mu\nu}u_r)\tau^I(D^\rho\widetilde H)(D_\rho W^I_{\mu\nu})$
$Q^{(1)}_{quBHD^2}$	$(\bar q_p\sigma^{\mu\nu}D^\rho u_r)(D_\nu\widetilde H)B_{\rho\mu}$
$Q^{(2)}_{quBHD^2}$	$(\bar q_p D^\rho u_r)(D^\nu\widetilde H)\widetilde B_{\rho\nu}$
$Q^{(3)}_{quBHD^2}$	$(\bar q_p\sigma^{\mu\nu}u_r)(D^\rho\widetilde H)(D_\rho B_{\mu\nu})$
$Q^{(1)}_{qdGHD^2}$	$(\bar q_p\sigma^{\mu\nu}T^A D^\rho d_r)(D_\nu H)G^A_{\rho\mu}$
$Q^{(2)}_{qdGHD^2}$	$(\bar q_p T^A D^\rho d_r)(D^\nu H)\widetilde G^A_{\rho\nu}$
$Q^{(3)}_{qdGHD^2}$	$(\bar q_p\sigma^{\mu\nu}T^A d_r)(D^\rho H)(D_\rho G^A_{\mu\nu})$
$Q^{(1)}_{qdWHD^2}$	$(\bar q_p\sigma^{\mu\nu}D^\rho d_r)\tau^I(D_\nu H)W^I_{\rho\mu}$
$Q^{(2)}_{qdWHD^2}$	$(\bar q_p D^\rho d_r)\tau^I(D^\nu H)\widetilde W^I_{\rho\nu}$
$Q^{(3)}_{qdWHD^2}$	$(\bar q_p\sigma^{\mu\nu}d_r)\tau^I(D^\rho H)(D_\rho W^I_{\mu\nu})$
$Q^{(1)}_{qdBHD^2}$	$(\bar q_p\sigma^{\mu\nu}D^\rho d_r)(D_\nu H)B_{\rho\mu}$
$Q^{(2)}_{qdBHD^2}$	$(\bar q_p D^\rho d_r)(D^\nu H)\widetilde B_{\rho\nu}$
$Q^{(3)}_{qdBHD^2}$	$(\bar q_p\sigma^{\mu\nu}d_r)(D^\rho H)(D_\rho B_{\mu\nu})$

17 : $\psi^2 H^3 D^2$ + h.c.

$Q^{(1)}_{leH^3D^2}$	$(D_\mu H^\dagger D^\mu H)(\bar l_p e_r H)$
$Q^{(2)}_{leH^3D^2}$	$(D_\mu H^\dagger\tau^I D^\mu H)(\bar l_p e_r\tau^I H)$
$Q^{(3)}_{leH^3D^2}$	$(D_\mu H^\dagger D_\nu H)(\bar l_p\sigma^{\mu\nu}e_r H)$
$Q^{(4)}_{leH^3D^2}$	$(D_\mu H^\dagger\tau^I D_\nu H)(\bar l_p\sigma^{\mu\nu}e_r\tau^I H)$
$Q^{(5)}_{leH^3D^2}$	$(H^\dagger D_\mu H)(\bar l_p e_r D^\mu H)$
$Q^{(6)}_{leH^3D^2}$	$(H^\dagger D_\mu H)(\bar l_p\sigma^{\mu\nu}e_r D_\nu H)$
$Q^{(1)}_{quH^3D^2}$	$(D_\mu H^\dagger D^\mu H)(\bar q_p u_r\widetilde H)$
$Q^{(2)}_{quH^3D^2}$	$(D_\mu H^\dagger\tau^I D^\mu H)(\bar q_p u_r\tau^I\widetilde H)$
$Q^{(3)}_{quH^3D^2}$	$(D_\mu H^\dagger D_\nu H)(\bar q_p\sigma^{\mu\nu}u_r\widetilde H)$
$Q^{(4)}_{quH^3D^2}$	$(D_\mu H^\dagger\tau^I D_\nu H)(\bar q_p\sigma^{\mu\nu}u_r\tau^I\widetilde H)$
$Q^{(5)}_{quH^3D^2}$	$(D_\mu H^\dagger H)(\bar q_p u_r D^\mu\widetilde H)$
$Q^{(6)}_{quH^3D^2}$	$(D_\mu H^\dagger H)(\bar q_p\sigma^{\mu\nu}u_r D_\nu\widetilde H)$
$Q^{(1)}_{qdH^3D^2}$	$(D_\mu H^\dagger D^\mu H)(\bar q_p d_r H)$
$Q^{(2)}_{qdH^3D^2}$	$(D_\mu H^\dagger\tau^I D^\mu H)(\bar q_p d_r\tau^I H)$
$Q^{(3)}_{qdH^3D^2}$	$(D_\mu H^\dagger D_\nu H)(\bar q_p\sigma^{\mu\nu}d_r H)$
$Q^{(4)}_{qdH^3D^2}$	$(D_\mu H^\dagger\tau^I D_\nu H)(\bar q_p\sigma^{\mu\nu}d_r\tau^I H)$
$Q^{(5)}_{qdH^3D^2}$	$(H^\dagger D_\mu H)(\bar q_p d_r D^\mu H)$
$Q^{(6)}_{qdH^3D^2}$	$(H^\dagger D_\mu H)(\bar q_p\sigma^{\mu\nu}d_r D_\nu H)$

SMEFT at $d = 8$: Murphy basis

Murphy 2206.07722
see also: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008

$18 : (\bar{L}R)(\bar{R}L)H^2 + \text{h.c.}$

$Q^{(1)}_{leqdH^2}$	$(\bar{l}^j_p e_r)(\bar{d}_s q_{tj})(H^\dagger H)$
$Q^{(2)}_{leqdH^2}$	$(\bar{l}_p e_r)\tau^I(\bar{d}_s q_t)(H^\dagger \tau^I H)$
$Q_{l^2udH^2}$	$(\bar{l}_p d_r H)(\widetilde{H}^\dagger \bar{u}_s l_t)$
$Q^{(5)}_{lequH^2}$	$(\bar{l}_p e_r H)(\widetilde{H}^\dagger \bar{u}_s q_t)$
$Q^{(5)}_{q^2udH^2}$	$(\bar{q}_p d_r H)(\widetilde{H}^\dagger \bar{u}_s q_t)$
$Q^{(6)}_{q^2udH^2}$	$(\bar{q}_p T^A d_r H)(\widetilde{H}^\dagger \bar{u}_s T^A q_t)$

$18(\not{B}) : \psi^4 H^2 + \text{h.c.}$

$Q^{(1)}_{lqudH^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(d^\alpha_p C u^\beta_r)(q^{j\gamma}_s C l^k_t)(H^\dagger H)$
$Q^{(2)}_{lqudH^2}$	$\epsilon_{\alpha\beta\gamma}(\epsilon\tau^I)_{jk}(d^\alpha_p C u^\beta_r)(q^{j\gamma}_s C l^k_t)(H^\dagger \tau^I H)$
$Q_{eq^2uH^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(q^{j\alpha}_p C q^{m\beta}_r)(u^\gamma_s C e_t)(H^\dagger_m H^k)$
$Q^{(1)}_{lq^3H^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{mn}\epsilon_{jk}(q^{m\alpha}_p C q^{j\beta}_r)(q^{k\gamma}_s C l^n_t)(H^\dagger H)$
$Q^{(2)}_{lq^3H^2}$	$\epsilon_{\alpha\beta\gamma}(\epsilon\tau^I)_{mn}\epsilon_{jk}(q^{m\alpha}_p C q^{j\beta}_r)(q^{k\gamma}_s C l^n_t)(H^\dagger \tau^I H)$
$Q_{eu^2dH^2}$	$\epsilon_{\alpha\beta\gamma}(d^\alpha_p C u^\beta_r)(u^\gamma_s C e_t)(H^\dagger H)$
$Q^{(3)}_{lq^3H^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{mn}(\epsilon\tau^I)_{jk}(q^{m\alpha}_p C q^{j\beta}_r)(q^{k\gamma}_s C l^n_t)(H^\dagger \tau^I H)$
$Q_{lqu^2H^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}\epsilon_{mn}(l^j_p C q^{m\alpha}_r)(u^\beta_s C u^\gamma_t)\widetilde{H}^k \widetilde{H}^n$
$Q_{lqd^2H^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}\epsilon_{mn}(l^j_p q^{m\alpha}_r)(d^\beta_s C d^\gamma_t)H^k H^n$
$Q_{eq^2dH^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}\epsilon_{mn}(e_p d^\alpha_r)(q^{j\beta}_s C q^{m\gamma}_t)H^k H^n$

$21 : (\bar{L}R)(\bar{R}L)D^2 + \text{h.c.}$

$Q^{(1)}_{leqdD^2}$	$D_\mu(\bar{l}^j_p e_r)D^\mu(\bar{d}_s q_{tj})$
$Q^{(2)}_{leqdD^2}$	$(\bar{l}^j_p \overleftrightarrow{D}_\mu e_r)(\bar{d}_s \overleftrightarrow{D}^\mu q_{tj})$

$21(\not{B}) : \psi^4 D^2 + \text{h.c.}$

$Q^{(1)}_{lqudD^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}D_\mu(d^\alpha_p C u^\beta_r)D^\mu(q^{j\gamma}_s C l^k_t)$
$Q^{(2)}_{lqudD^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}D_\mu(d^\alpha_p C q^{j\beta}_r)D^\mu(u^\gamma_s C l^k_t)$
$Q_{eq^2uD^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(q^{j\alpha}_p C D_\mu q^{k\beta}_r)D^\mu(u^\gamma_s C e_t)$
$Q_{lq^3D^2}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{mn}\epsilon_{jk}(q^{m\alpha}_p C D_\mu q^{j\beta}_r)D^\mu(q^{k\gamma}_s C l^n_t)$
$Q^{(1)}_{eu^2dD^2}$	$\epsilon_{\alpha\beta\gamma}(u^\alpha_p C D_\mu u^\beta_r)D^\mu(d^\gamma_s C e_t)$
$Q^{(2)}_{eu^2dD^2}$	$\epsilon_{\alpha\beta\gamma}(u^\alpha_p C u^\beta_r)(D_\mu d^\gamma_s C D^\mu e_t)$

$18 : (\bar{L}L)(\bar{L}L)H^2$

$Q^{(1)}_{l^4H^2}$	$(\bar{l}_p\gamma^\mu l_r)(\bar{l}_s\gamma_\mu l_t)(H^\dagger H)$
$Q^{(2)}_{l^4H^2}$	$(\bar{l}_p\gamma^\mu l_r)(\bar{l}_s\gamma_\mu\tau^I l_t)(H^\dagger\tau^I H)$
$Q^{(1)}_{q^4H^2}$	$(\bar{q}_p\gamma^\mu q_r)(\bar{q}_s\gamma_\mu q_t)(H^\dagger H)$
$Q^{(2)}_{q^4H^2}$	$(\bar{q}_p\gamma^\mu q_r)(\bar{q}_s\gamma_\mu\tau^I q_t)(H^\dagger\tau^I H)$
$Q^{(3)}_{q^4H^2}$	$(\bar{q}_p\gamma^\mu\tau^I q_r)(\bar{q}_s\gamma_\mu\tau^I q_t)(H^\dagger H)$
$Q^{(1)}_{l^2q^2H^2}$	$(\bar{l}_p\gamma^\mu l_r)(\bar{q}_s\gamma_\mu q_t)(H^\dagger H)$
$Q^{(2)}_{l^2q^2H^2}$	$(\bar{l}_p\gamma^\mu\tau^I l_r)(\bar{q}_s\gamma_\mu q_t)(H^\dagger\tau^I H)$
$Q^{(3)}_{l^2q^2H^2}$	$(\bar{l}_p\gamma^\mu\tau^I l_r)(\bar{q}_s\gamma_\mu\tau^I q_t)(H^\dagger H)$
$Q^{(4)}_{l^2q^2H^2}$	$(\bar{l}_p\gamma^\mu l_r)(\bar{q}_s\gamma_\mu\tau^I q_t)(H^\dagger\tau^I H)$
$Q^{(5)}_{l^2q^2H^2}$	$\epsilon^{IJK}(\bar{l}_p\gamma^\mu\tau^I l_r)(\bar{q}_s\gamma_\mu\tau^J q_t)(H^\dagger\tau^K H)$
$Q^{(5)}_{q^4H^2}$	$\epsilon^{IJK}(\bar{q}_p\gamma^\mu\tau^I q_r)(\bar{q}_s\gamma_\mu\tau^J q_t)(H^\dagger\tau^K H)$

$18 : (\bar{R}R)(\bar{R}R)H^2$

$Q_{e^4H^2}$	$(\bar{e}_p\gamma^\mu e_r)(\bar{e}_s\gamma_\mu e_t)(H^\dagger H)$
$Q_{u^4H^2}$	$(\bar{u}_p\gamma^\mu u_r)(\bar{u}_s\gamma_\mu u_t)(H^\dagger H)$
$Q_{d^4H^2}$	$(\bar{d}_p\gamma^\mu d_r)(\bar{d}_s\gamma_\mu d_t)(H^\dagger H)$
$Q_{e^2u^2H^2}$	$(\bar{e}_p\gamma^\mu e_r)(\bar{u}_s\gamma_\mu u_t)(H^\dagger H)$
$Q_{e^2d^2H^2}$	$(\bar{e}_p\gamma^\mu e_r)(\bar{d}_s\gamma_\mu d_t)(H^\dagger H)$
$Q^{(1)}_{u^2d^2H^2}$	$(\bar{u}_p\gamma^\mu u_r)(\bar{d}_s\gamma_\mu d_t)(H^\dagger H)$
$Q^{(2)}_{u^2d^2H^2}$	$(\bar{u}_p\gamma^\mu T^A u_r)(\bar{d}_s\gamma_\mu T^A d_t)(H^\dagger H)$

$18 : (\bar{L}L)(\bar{R}R)H^2$

$Q^{(1)}_{l^2e^2H^2}$	$(\bar{l}_p\gamma^\mu l_r)(\bar{e}_s\gamma_\mu e_t)(H^\dagger H)$
$Q^{(2)}_{l^2e^2H^2}$	$(\bar{l}_p\gamma^\mu\tau^I l_r)(\bar{e}_s\gamma_\mu e_t)(H^\dagger\tau^I H)$
$Q^{(1)}_{l^2u^2H^2}$	$(\bar{l}_p\gamma^\mu l_r)(\bar{u}_s\gamma_\mu u_t)(H^\dagger H)$
$Q^{(2)}_{l^2u^2H^2}$	$(\bar{l}_p\gamma^\mu\tau^I l_r)(\bar{u}_s\gamma_\mu u_t)(H^\dagger\tau^I H)$
$Q^{(1)}_{l^2d^2H^2}$	$(\bar{l}_p\gamma^\mu l_r)(\bar{d}_s\gamma_\mu d_t)(H^\dagger H)$
$Q^{(2)}_{l^2d^2H^2}$	$(\bar{l}_p\gamma^\mu\tau^I l_r)(\bar{d}_s\gamma_\mu d_t)(H^\dagger\tau^I H)$
$Q^{(1)}_{q^2e^2H^2}$	$(\bar{q}_p\gamma^\mu q_r)(\bar{e}_s\gamma_\mu e_t)(H^\dagger H)$
$Q^{(2)}_{q^2e^2H^2}$	$(\bar{q}_p\gamma^\mu\tau^I q_r)(\bar{e}_s\gamma_\mu e_t)(H^\dagger\tau^I H)$
$Q^{(1)}_{q^2u^2H^2}$	$(\bar{q}_p\gamma^\mu q_r)(\bar{u}_s\gamma_\mu u_t)(H^\dagger H)$
$Q^{(2)}_{q^2u^2H^2}$	$(\bar{q}_p\gamma^\mu\tau^I q_r)(\bar{u}_s\gamma_\mu u_t)(H^\dagger\tau^I H)$
$Q^{(3)}_{q^2u^2H^2}$	$(\bar{q}_p\gamma^\mu T^A q_r)(\bar{u}_s\gamma_\mu T^A u_t)(H^\dagger H)$
$Q^{(4)}_{q^2u^2H^2}$	$(\bar{q}_p\gamma^\mu T^A\tau^I q_r)(\bar{u}_s\gamma_\mu T^A u_t)(H^\dagger\tau^I H)$
$Q^{(1)}_{q^2d^2H^2}$	$(\bar{q}_p\gamma^\mu q_r)(\bar{d}_s\gamma_\mu d_t)(H^\dagger H)$
$Q^{(2)}_{q^2d^2H^2}$	$(\bar{q}_p\gamma^\mu\tau^I q_r)(\bar{d}_s\gamma_\mu d_t)(H^\dagger\tau^I H)$
$Q^{(3)}_{q^2d^2H^2}$	$(\bar{q}_p\gamma^\mu T^A q_r)(\bar{d}_s\gamma_\mu T^A d_t)(H^\dagger H)$
$Q^{(4)}_{q^2d^2H^2}$	$(\bar{q}_p\gamma^\mu T^A\tau^I q_r)(\bar{d}_s\gamma_\mu T^A d_t)(H^\dagger\tau^I H)$

$18 : (\bar{L}R)(\bar{L}R)H^2 + \text{h.c.}$

$Q^{(1)}_{q^2udH^2}$	$(\bar{q}^j_p u_r)\epsilon_{jk}(\bar{q}^k_s d_t)(H^\dagger H)$
$Q^{(2)}_{q^2udH^2}$	$(\bar{q}^j_p u_r)(\tau^I\epsilon)_{jk}(\bar{q}^k_s d_t)(H^\dagger\tau^I H)$
$Q^{(3)}_{q^2udH^2}$	$(\bar{q}^j_p T^A u_r)\epsilon_{jk}(\bar{q}^k_s T^A d_t)(H^\dagger H)$
$Q^{(4)}_{q^2udH^2}$	$(\bar{q}^j_p T^A u_r)(\tau^I\epsilon)_{jk}(\bar{q}^k_s T^A d_t)(H^\dagger\tau^I H)$
$Q^{(1)}_{lequH^2}$	$(\bar{l}^j_p e_r)\epsilon_{jk}(\bar{q}^k_s u_t)(H^\dagger H)$
$Q^{(2)}_{lequH^2}$	$(\bar{l}^j_p e_r)(\tau^I\epsilon)_{jk}(\bar{q}^k_s u_t)(H^\dagger\tau^I H)$
$Q^{(3)}_{lequH^2}$	$(\bar{l}^j_p\sigma_{\mu\nu}e_r)\epsilon_{jk}(\bar{q}^k_s\sigma^{\mu\nu}u_t)(H^\dagger H)$
$Q^{(4)}_{lequH^2}$	$(\bar{l}^j_p\sigma_{\mu\nu}e_r)(\tau^I\epsilon)_{jk}(\bar{q}^k_s\sigma^{\mu\nu}u_t)(H^\dagger\tau^I H)$
$Q^{(3)}_{l^2e^2H^2}$	$(\bar{l}_p e_r H)(\bar{l}_s e_t H)$
$Q^{(3)}_{leqdH^2}$	$(\bar{l}_p e_r H)(\bar{q}_s d_t H)$
$Q^{(4)}_{leqdH^2}$	$(\bar{l}_p\sigma_{\mu\nu}e_r H)(\bar{q}_s\sigma^{\mu\nu}d_t H)$
$Q^{(5)}_{q^2u^2H^2}$	$(\bar{q}_p u_r\widetilde{H})(\bar{q}_s u_t\widetilde{H})$
$Q^{(6)}_{q^2u^2H^2}$	$(\bar{q}_p T^A u_r\widetilde{H})(\bar{q}_s T^A u_t\widetilde{H})$
$Q^{(5)}_{q^2d^2H^2}$	$(\bar{q}_p d_r H)(\bar{q}_s d_t H)$
$Q^{(6)}_{q^2d^2H^2}$	$(\bar{q}_p T^A d_r H)(\bar{q}_s T^A d_t H)$

SMEFT at $d=8$: Murphy basis

Murphy 2206.07722
see also: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008

$19:(\bar LL)(\bar LL)X$	
$Q^{(1)}_{l^4W}$	$(\bar l_p\gamma^\mu l_r)(\bar l_s\gamma^\nu\tau^I l_t)W^I_{\mu\nu}$
$Q^{(2)}_{l^4W}$	$(\bar l_p\gamma^\mu l_r)(\bar l_s\gamma^\nu\tau^I l_t)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{q^4G}$	$(\bar q_p\gamma^\mu q_r)(\bar q_s\gamma^\nu T^A q_t)G^A_{\mu\nu}$
$Q^{(2)}_{q^4G}$	$(\bar q_p\gamma^\mu q_r)(\bar q_s\gamma^\nu T^A q_t)\widetilde G^A_{\mu\nu}$
$Q^{(3)}_{q^4G}$	$(\bar q_p\gamma^\mu\tau^I q_r)(\bar q_s\gamma^\nu T^A\tau^I q_t)G^A_{\mu\nu}$
$Q^{(4)}_{q^4G}$	$(\bar q_p\gamma^\mu\tau^I q_r)(\bar q_s\gamma^\nu T^A\tau^I q_t)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{q^4W}$	$(\bar q_p\gamma^\mu q_r)(\bar q_s\gamma^\nu\tau^I q_t)W^I_{\mu\nu}$
$Q^{(2)}_{q^4W}$	$(\bar q_p\gamma^\mu q_r)(\bar q_s\gamma^\nu\tau^I q_t)\widetilde W^I_{\mu\nu}$
$Q^{(3)}_{q^4W}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar q_s\gamma^\nu T^A\tau^I q_t)W^I_{\mu\nu}$
$Q^{(4)}_{q^4W}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar q_s\gamma^\nu T^A\tau^I q_t)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{l^2q^2G}$	$(\bar l_p\gamma^\mu l_r)(\bar q_s\gamma^\nu T^A q_t)G^A_{\mu\nu}$
$Q^{(2)}_{l^2q^2G}$	$(\bar l_p\gamma^\mu l_r)(\bar q_s\gamma^\nu T^A q_t)\widetilde G^A_{\mu\nu}$
$Q^{(3)}_{l^2q^2G}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar q_s\gamma^\nu T^A\tau^I q_t)G^A_{\mu\nu}$
$Q^{(4)}_{l^2q^2G}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar q_s\gamma^\nu T^A\tau^I q_t)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{l^2q^2W}$	$(\bar l_p\gamma^\mu l_r)(\bar q_s\gamma^\nu\tau^I q_t)W^I_{\mu\nu}$
$Q^{(2)}_{l^2q^2W}$	$(\bar l_p\gamma^\mu l_r)(\bar q_s\gamma^\nu\tau^I q_t)\widetilde W^I_{\mu\nu}$
$Q^{(3)}_{l^2q^2W}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar q_s\gamma^\nu q_t)W^I_{\mu\nu}$
$Q^{(4)}_{l^2q^2W}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar q_s\gamma^\nu q_t)\widetilde W^I_{\mu\nu}$
$Q^{(5)}_{l^2q^2W}$	$\epsilon^{IJK}(\bar l_p\gamma^\mu\tau^I l_r)(\bar q_s\gamma^\nu\tau^J q_t)W^K_{\mu\nu}$
$Q^{(6)}_{l^2q^2W}$	$\epsilon^{IJK}(\bar l_p\gamma^\mu\tau^I l_r)(\bar q_s\gamma^\nu\tau^J q_t)\widetilde W^K_{\mu\nu}$
$Q^{(1)}_{l^2q^2B}$	$(\bar l_p\gamma^\mu l_r)(\bar q_s\gamma^\nu q_t)B_{\mu\nu}$
$Q^{(2)}_{l^2q^2B}$	$(\bar l_p\gamma^\mu l_r)(\bar q_s\gamma^\nu q_t)\widetilde B_{\mu\nu}$
$Q^{(3)}_{l^2q^2B}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar q_s\gamma^\nu\tau^I q_t)B_{\mu\nu}$
$Q^{(4)}_{l^2q^2B}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar q_s\gamma^\nu\tau^I q_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{l^4B}$	$(\bar l_p\gamma^\mu l_r)(\bar l_s\gamma^\nu l_t)B_{\mu\nu}$
$Q^{(2)}_{l^4B}$	$(\bar l_p\gamma^\mu l_r)(\bar l_s\gamma^\nu l_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{q^4B}$	$(\bar q_p\gamma^\mu q_r)(\bar q_s\gamma^\nu q_t)B_{\mu\nu}$
$Q^{(2)}_{q^4B}$	$(\bar q_p\gamma^\mu q_r)(\bar q_s\gamma^\nu q_t)\widetilde B_{\mu\nu}$
$Q^{(3)}_{q^4B}$	$(\bar q_p\gamma^\mu\tau^I q_r)(\bar q_s\gamma^\nu\tau^I q_t)B_{\mu\nu}$
$Q^{(4)}_{q^4B}$	$(\bar q_p\gamma^\mu\tau^I q_r)(\bar q_s\gamma^\nu\tau^I q_t)\widetilde B_{\mu\nu}$

$19:(\bar RR)(\bar RR)X$	
$Q^{(1)}_{u^4G}$	$(\bar u_p\gamma^\mu u_r)(\bar u_s\gamma^\nu T^A u_t)G^A_{\mu\nu}$
$Q^{(2)}_{u^4G}$	$(\bar u_p\gamma^\mu u_r)(\bar u_s\gamma^\nu T^A u_t)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{d^4G}$	$(\bar d_p\gamma^\mu d_r)(\bar d_s\gamma^\nu T^A d_t)G^A_{\mu\nu}$
$Q^{(2)}_{d^4G}$	$(\bar d_p\gamma^\mu d_r)(\bar d_s\gamma^\nu T^A d_t)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{e^2u^2G}$	$(\bar e_p\gamma^\mu e_r)(\bar u_s\gamma^\nu T^A u_t)G^A_{\mu\nu}$
$Q^{(2)}_{e^2u^2G}$	$(\bar e_p\gamma^\mu e_r)(\bar u_s\gamma^\nu T^A u_t)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{e^2u^2B}$	$(\bar e_p\gamma^\mu e_r)(\bar u_s\gamma^\nu u_t)B_{\mu\nu}$
$Q^{(2)}_{e^2u^2B}$	$(\bar e_p\gamma^\mu e_r)(\bar u_s\gamma^\nu u_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{e^2d^2G}$	$(\bar e_p\gamma^\mu e_r)(\bar d_s\gamma^\nu T^A d_t)G^A_{\mu\nu}$
$Q^{(2)}_{e^2d^2G}$	$(\bar e_p\gamma^\mu e_r)(\bar d_s\gamma^\nu T^A d_t)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{e^2d^2B}$	$(\bar e_p\gamma^\mu e_r)(\bar d_s\gamma^\nu d_t)B_{\mu\nu}$
$Q^{(2)}_{e^2d^2B}$	$(\bar e_p\gamma^\mu e_r)(\bar d_s\gamma^\nu d_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{u^2d^2G}$	$(\bar u_p\gamma^\mu u_r)(\bar d_s\gamma^\nu T^A d_t)G^A_{\mu\nu}$
$Q^{(2)}_{u^2d^2G}$	$(\bar u_p\gamma^\mu u_r)(\bar d_s\gamma^\nu T^A d_t)\widetilde G^A_{\mu\nu}$
$Q^{(3)}_{u^2d^2G}$	$(\bar u_p\gamma^\mu T^A u_r)(\bar d_s\gamma^\nu d_t)G^A_{\mu\nu}$
$Q^{(4)}_{u^2d^2G}$	$(\bar u_p\gamma^\mu T^A u_r)(\bar d_s\gamma^\nu d_t)\widetilde G^A_{\mu\nu}$
$Q^{(5)}_{u^2d^2G}$	$f^{ABC}(\bar u_p\gamma^\mu T^A u_r)(\bar d_s\gamma^\nu T^B d_t)G^C_{\mu\nu}$
$Q^{(6)}_{u^2d^2G}$	$f^{ABC}(\bar u_p\gamma^\mu T^A u_r)(\bar d_s\gamma^\nu T^B d_t)\widetilde G^C_{\mu\nu}$
$Q^{(7)}_{u^2d^2G}$	$d^{ABC}(\bar u_p\gamma^\mu T^A u_r)(\bar d_s\gamma^\nu T^B d_t)G^C_{\mu\nu}$
$Q^{(8)}_{u^2d^2G}$	$d^{ABC}(\bar u_p\gamma^\mu T^A u_r)(\bar d_s\gamma^\nu T^B d_t)\widetilde G^C_{\mu\nu}$
$Q^{(1)}_{u^2d^2B}$	$(\bar u_p\gamma^\mu u_r)(\bar d_s\gamma^\nu d_t)B_{\mu\nu}$
$Q^{(2)}_{u^2d^2B}$	$(\bar u_p\gamma^\mu u_r)(\bar d_s\gamma^\nu d_t)\widetilde B_{\mu\nu}$
$Q^{(3)}_{u^2d^2B}$	$(\bar u_p\gamma^\mu T^A u_r)(\bar d_s\gamma^\nu T^A d_t)B_{\mu\nu}$
$Q^{(4)}_{u^2d^2B}$	$(\bar u_p\gamma^\mu T^A u_r)(\bar d_s\gamma^\nu T^A d_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{e^4B}$	$(\bar e_p\gamma^\mu e_r)(\bar e_s\gamma^\nu e_t)B_{\mu\nu}$
$Q^{(2)}_{e^4B}$	$(\bar e_p\gamma^\mu e_r)(\bar e_s\gamma^\nu e_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{u^4B}$	$(\bar u_p\gamma^\mu u_r)(\bar u_s\gamma^\nu u_t)B_{\mu\nu}$
$Q^{(2)}_{u^4B}$	$(\bar u_p\gamma^\mu u_r)(\bar u_s\gamma^\nu u_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{d^4B}$	$(\bar d_p\gamma^\mu d_r)(\bar d_s\gamma^\nu d_t)B_{\mu\nu}$
$Q^{(2)}_{d^4B}$	$(\bar d_p\gamma^\mu d_r)(\bar d_s\gamma^\nu d_t)\widetilde B_{\mu\nu}$

$19:(\bar LL)(\bar RR)X$	
$Q^{(1)}_{l^2e^2W}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar e_s\gamma^\nu e_t)W^I_{\mu\nu}$
$Q^{(2)}_{l^2e^2W}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar e_s\gamma^\nu e_t)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{l^2e^2B}$	$(\bar l_p\gamma^\mu l_r)(\bar e_s\gamma^\nu e_t)B_{\mu\nu}$
$Q^{(2)}_{l^2e^2B}$	$(\bar l_p\gamma^\mu l_r)(\bar e_s\gamma^\nu e_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{l^2u^2G}$	$(\bar l_p\gamma^\mu l_r)(\bar u_s\gamma^\nu T^A u_t)G^A_{\mu\nu}$
$Q^{(2)}_{l^2u^2G}$	$(\bar l_p\gamma^\mu l_r)(\bar u_s\gamma^\nu T^A u_t)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{l^2u^2W}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar u_s\gamma^\nu u_t)W^I_{\mu\nu}$
$Q^{(2)}_{l^2u^2W}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar u_s\gamma^\nu u_t)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{l^2u^2B}$	$(\bar l_p\gamma^\mu l_r)(\bar u_s\gamma^\nu u_t)B_{\mu\nu}$
$Q^{(2)}_{l^2u^2B}$	$(\bar l_p\gamma^\mu l_r)(\bar u_s\gamma^\nu u_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{l^2d^2G}$	$(\bar l_p\gamma^\mu l_r)(\bar d_s\gamma^\nu T^A d_t)G^A_{\mu\nu}$
$Q^{(2)}_{l^2d^2G}$	$(\bar l_p\gamma^\mu l_r)(\bar d_s\gamma^\nu T^A d_t)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{l^2d^2W}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar d_s\gamma^\nu d_t)W^I_{\mu\nu}$
$Q^{(2)}_{l^2d^2W}$	$(\bar l_p\gamma^\mu\tau^I l_r)(\bar d_s\gamma^\nu d_t)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{l^2d^2B}$	$(\bar l_p\gamma^\mu l_r)(\bar d_s\gamma^\nu d_t)B_{\mu\nu}$
$Q^{(2)}_{l^2d^2B}$	$(\bar l_p\gamma^\mu l_r)(\bar d_s\gamma^\nu d_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{q^2e^2G}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar e_s\gamma^\nu e_t)G^A_{\mu\nu}$
$Q^{(2)}_{q^2e^2G}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar e_s\gamma^\nu e_t)\widetilde G^A_{\mu\nu}$
$Q^{(1)}_{q^2e^2W}$	$(\bar q_p\gamma^\mu\tau^I q_r)(\bar e_s\gamma^\nu e_t)W^I_{\mu\nu}$
$Q^{(2)}_{q^2e^2W}$	$(\bar q_p\gamma^\mu\tau^I q_r)(\bar e_s\gamma^\nu e_t)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{q^2e^2B}$	$(\bar q_p\gamma^\mu q_r)(\bar e_s\gamma^\nu e_t)B_{\mu\nu}$
$Q^{(2)}_{q^2e^2B}$	$(\bar q_p\gamma^\mu q_r)(\bar e_s\gamma^\nu e_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{q^2u^2G}$	$(\bar q_p\gamma^\mu q_r)(\bar u_s\gamma^\nu T^A u_t)G^A_{\mu\nu}$
$Q^{(2)}_{q^2u^2G}$	$(\bar q_p\gamma^\mu q_r)(\bar u_s\gamma^\nu T^A u_t)\widetilde G^A_{\mu\nu}$
$Q^{(3)}_{q^2u^2G}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar u_s\gamma^\nu u_t)G^A_{\mu\nu}$
$Q^{(4)}_{q^2u^2G}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar u_s\gamma^\nu u_t)\widetilde G^A_{\mu\nu}$

$19:(\bar LL)(\bar RR)X$	
$Q^{(5)}_{q^2u^2G}$	$f^{ABC}(\bar q_p\gamma^\mu T^A q_r)(\bar u_s\gamma^\nu T^B u_t)G^C_{\mu\nu}$
$Q^{(6)}_{q^2u^2G}$	$f^{ABC}(\bar q_p\gamma^\mu T^A q_r)(\bar u_s\gamma^\nu T^B u_t)\widetilde G^C_{\mu\nu}$
$Q^{(7)}_{q^2u^2G}$	$d^{ABC}(\bar q_p\gamma^\mu T^A q_r)(\bar u_s\gamma^\nu T^B u_t)G^C_{\mu\nu}$
$Q^{(8)}_{q^2u^2G}$	$d^{ABC}(\bar q_p\gamma^\mu T^A q_r)(\bar u_s\gamma^\nu T^B u_t)\widetilde G^C_{\mu\nu}$
$Q^{(1)}_{q^2u^2W}$	$(\bar q_p\gamma^\mu\tau^I q_r)(\bar u_s\gamma^\nu u_t)W^I_{\mu\nu}$
$Q^{(2)}_{q^2u^2W}$	$(\bar q_p\gamma^\mu\tau^I q_r)(\bar u_s\gamma^\nu u_t)\widetilde W^I_{\mu\nu}$
$Q^{(3)}_{q^2u^2W}$	$(\bar q_p\gamma^\mu T^A\tau^I q_r)(\bar u_s\gamma^\nu T^A u_t)W^I_{\mu\nu}$
$Q^{(4)}_{q^2u^2W}$	$(\bar q_p\gamma^\mu T^A\tau^I q_r)(\bar u_s\gamma^\nu T^A u_t)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{q^2u^2B}$	$(\bar q_p\gamma^\mu q_r)(\bar u_s\gamma^\nu u_t)B_{\mu\nu}$
$Q^{(2)}_{q^2u^2B}$	$(\bar q_p\gamma^\mu q_r)(\bar u_s\gamma^\nu u_t)\widetilde B_{\mu\nu}$
$Q^{(3)}_{q^2u^2B}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar u_s\gamma^\nu T^A u_t)B_{\mu\nu}$
$Q^{(4)}_{q^2u^2B}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar u_s\gamma^\nu T^A u_t)\widetilde B_{\mu\nu}$
$Q^{(1)}_{q^2d^2G}$	$(\bar q_p\gamma^\mu q_r)(\bar d_s\gamma^\nu T^A d_t)G^A_{\mu\nu}$
$Q^{(2)}_{q^2d^2G}$	$(\bar q_p\gamma^\mu q_r)(\bar d_s\gamma^\nu T^A d_t)\widetilde G^A_{\mu\nu}$
$Q^{(3)}_{q^2d^2G}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar d_s\gamma^\nu d_t)G^A_{\mu\nu}$
$Q^{(4)}_{q^2d^2G}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar d_s\gamma^\nu d_t)\widetilde G^A_{\mu\nu}$
$Q^{(5)}_{q^2d^2G}$	$f^{ABC}(\bar q_p\gamma^\mu T^A q_r)(\bar d_s\gamma^\nu T^B d_t)G^C_{\mu\nu}$
$Q^{(6)}_{q^2d^2G}$	$f^{ABC}(\bar q_p\gamma^\mu T^A q_r)(\bar d_s\gamma^\nu T^B d_t)\widetilde G^C_{\mu\nu}$
$Q^{(7)}_{q^2d^2G}$	$d^{ABC}(\bar q_p\gamma^\mu T^A q_r)(\bar d_s\gamma^\nu T^B d_t)G^C_{\mu\nu}$
$Q^{(8)}_{q^2d^2G}$	$d^{ABC}(\bar q_p\gamma^\mu T^A q_r)(\bar d_s\gamma^\nu T^B d_t)\widetilde G^C_{\mu\nu}$
$Q^{(1)}_{q^2d^2W}$	$(\bar q_p\gamma^\mu\tau^I q_r)(\bar d_s\gamma^\nu d_t)W^I_{\mu\nu}$
$Q^{(2)}_{q^2d^2W}$	$(\bar q_p\gamma^\mu\tau^I q_r)(\bar d_s\gamma^\nu d_t)\widetilde W^I_{\mu\nu}$
$Q^{(3)}_{q^2d^2W}$	$(\bar q_p\gamma^\mu T^A\tau^I q_r)(\bar d_s\gamma^\nu T^A d_t)W^I_{\mu\nu}$
$Q^{(4)}_{q^2d^2W}$	$(\bar q_p\gamma^\mu T^A\tau^I q_r)(\bar d_s\gamma^\nu T^A d_t)\widetilde W^I_{\mu\nu}$
$Q^{(1)}_{q^2d^2B}$	$(\bar q_p\gamma^\mu q_r)(\bar d_s\gamma^\nu d_t)B_{\mu\nu}$
$Q^{(2)}_{q^2d^2B}$	$(\bar q_p\gamma^\mu q_r)(\bar d_s\gamma^\nu d_t)\widetilde B_{\mu\nu}$
$Q^{(3)}_{q^2d^2B}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar d_s\gamma^\nu T^A d_t)B_{\mu\nu}$
$Q^{(4)}_{q^2d^2B}$	$(\bar q_p\gamma^\mu T^A q_r)(\bar d_s\gamma^\nu T^A d_t)\widetilde B_{\mu\nu}$

SMEFT at $d=8$: Murphy basis

$\mathbf{19:(\bar{L}R)(\bar{R}L)X+\text{h.c.}}$	
$Q^{(1)}_{ledqG}$	$(\bar{l}^j_p\sigma^{\mu\nu}e_r)(\bar{d}_sT^Aq_{tj})G^A_{\mu\nu}$
$Q^{(2)}_{ledqG}$	$(\bar{l}^j_pe_r)(\bar{d}_s\sigma^{\mu\nu}T^Aq_{tj})G^A_{\mu\nu}$
$Q^{(1)}_{ledqW}$	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I(\bar{d}_sq_t)W^I_{\mu\nu}$
$Q^{(2)}_{ledqW}$	$(\bar{l}_pe_r)\tau^I(\bar{d}_s\sigma^{\mu\nu}q_t)W^I_{\mu\nu}$
$Q^{(1)}_{ledqB}$	$(\bar{l}^j_p\sigma^{\mu\nu}e_r)(\bar{d}_sq_{tj})B_{\mu\nu}$
$Q^{(2)}_{ledqB}$	$(\bar{l}^j_pe_r)(\bar{d}_s\sigma^{\mu\nu}q_{tj})B_{\mu\nu}$

$\mathbf{19:(\bar{L}R)(\bar{L}R)X+\text{h.c.}}$	
$Q^{(1)}_{q^2udG}$	$(\bar{q}^j_p\sigma^{\mu\nu}T^Au_r)\epsilon_{jk}(\bar{q}^k_sd_t)G^A_{\mu\nu}$
$Q^{(2)}_{q^2udG}$	$(\bar{q}^j_p\sigma^{\mu\nu}u_r)\epsilon_{jk}(\bar{q}^k_sT^Ad_t)G^A_{\mu\nu}$
$Q^{(3)}_{q^2udG}$	$(\bar{q}^j_pT^Au_r)\epsilon_{jk}(\bar{q}^k_s\sigma^{\mu\nu}d_t)G^A_{\mu\nu}$
$Q^{(4)}_{q^2udG}$	$(\bar{q}^j_pu_r)\epsilon_{jk}(\bar{q}^k_s\sigma^{\mu\nu}T^Ad_t)G^A_{\mu\nu}$
$Q^{(5)}_{q^2udG}$	$(\bar{q}^j_p\sigma^{\mu\rho}T^Au_r)\epsilon_{jk}(\bar{q}^k_s\sigma_{\rho\nu}d_t)G^{A\nu}_{\mu}$
$Q^{(6)}_{q^2udG}$	$(\bar{q}^j_p\sigma^{\mu\rho}u_r)\epsilon_{jk}(\bar{q}^k_s\sigma_{\rho\nu}T^Ad_t)G^{A\nu}_{\mu}$
$Q^{(1)}_{q^2udW}$	$(\bar{q}^j_p\sigma^{\mu\nu}u_r)(\tau^I\epsilon)_{jk}(\bar{q}^k_sd_t)W^I_{\mu\nu}$
$Q^{(2)}_{q^2udW}$	$(\bar{q}^j_pu_r)(\tau^I\epsilon)_{jk}(\bar{q}^k_s\sigma^{\mu\nu}d_t)W^I_{\mu\nu}$
$Q^{(3)}_{q^2udW}$	$(\bar{q}^j_p\sigma^{\mu\rho}u_r)(\tau^I\epsilon)_{jk}(\bar{q}^k_s\sigma_{\rho\nu}d_t)W^{I\nu}_{\mu}$
$Q^{(1)}_{q^2udB}$	$(\bar{q}^j_p\sigma^{\mu\nu}u_r)\epsilon_{jk}(\bar{q}^k_sd_t)B_{\mu\nu}$
$Q^{(2)}_{q^2udB}$	$(\bar{q}^j_pu_r)\epsilon_{jk}(\bar{q}^k_s\sigma^{\mu\nu}d_t)B_{\mu\nu}$
$Q^{(3)}_{q^2udB}$	$(\bar{q}^j_p\sigma^{\mu\rho}u_r)\epsilon_{jk}(\bar{q}^k_s\sigma_{\rho\nu}d_t)B^{\nu}_{\mu}$
$Q^{(1)}_{lequG}$	$(\bar{l}^j_p\sigma^{\mu\nu}e_r)\epsilon_{jk}(\bar{q}^k_sT^Au_t)G^A_{\mu\nu}$
$Q^{(2)}_{lequG}$	$(\bar{l}^j_pe_r)\epsilon_{jk}(\bar{q}^k_s\sigma^{\mu\nu}T^Au_t)G^A_{\mu\nu}$
$Q^{(3)}_{lequG}$	$(\bar{l}^j_p\sigma^{\mu\rho}e_r)\epsilon_{jk}(\bar{q}^k_s\sigma_{\rho\nu}T^Au_t)G^{A\nu}_{\mu}$
$Q^{(1)}_{lequW}$	$(\bar{l}^j_p\sigma^{\mu\nu}e_r)(\tau^I\epsilon)_{jk}(\bar{q}^k_su_t)W^I_{\mu\nu}$
$Q^{(2)}_{lequW}$	$(\bar{l}^j_pe_r)(\tau^I\epsilon)_{jk}(\bar{q}^k_s\sigma^{\mu\nu}u_t)W^I_{\mu\nu}$
$Q^{(3)}_{lequW}$	$(\bar{l}^j_p\sigma^{\mu\rho}e_r)(\tau^I\epsilon)_{jk}(\bar{q}^k_s\sigma_{\rho\nu}u_t)W^{I\nu}_{\mu}$
$Q^{(1)}_{lequB}$	$(\bar{l}^j_p\sigma^{\mu\nu}e_r)\epsilon_{jk}(\bar{q}^k_su_t)B_{\mu\nu}$
$Q^{(2)}_{lequB}$	$(\bar{l}^j_pe_r)\epsilon_{jk}(\bar{q}^k_s\sigma^{\mu\nu}u_t)B_{\mu\nu}$
$Q^{(3)}_{lequB}$	$(\bar{l}^j_p\sigma^{\mu\rho}e_r)\epsilon_{jk}(\bar{q}^k_s\sigma_{\rho\nu}u_t)B^{\nu}_{\mu}$

$\mathbf{19(\not{B}):\psi^4X+\text{h.c.}}$	
$Q^{(1)}_{lqudG}$	$(T^A)^\delta_\gamma\epsilon_{\delta\alpha\beta}\epsilon_{jk}(d^\alpha_pC\sigma^{\mu\nu}u^\beta_r)(q^{j\gamma}_sCl^k_t)G^A_{\mu\nu}$
$Q^{(2)}_{lqudG}$	$(T^A)^\delta_\gamma\epsilon_{\delta\alpha\beta}\epsilon_{jk}(d^\alpha_pCu^\beta_r)(q^{j\gamma}_sC\sigma^{\mu\nu}l^k_t)G^A_{\mu\nu}$
$Q^{(3)}_{lqudG}$	$(T^A)^\delta_{(\alpha}\epsilon_{\beta)\gamma\delta}\epsilon_{jk}(d^\alpha_pC\sigma^{\mu\nu}u^\beta_r)(q^{j\gamma}_sCl^k_t)G^A_{\mu\nu}$
$Q^{(4)}_{lqudG}$	$(T^A)^\delta_{(\alpha}\epsilon_{\beta)\gamma\delta}\epsilon_{jk}(d^\alpha_pCu^\beta_r)(q^{j\gamma}_sC\sigma^{\mu\nu}l^k_t)G^A_{\mu\nu}$
$Q^{(1)}_{lqudW}$	$\epsilon_{\alpha\beta\gamma}(\epsilon\tau^I)_{jk}(d^\alpha_pC\sigma^{\mu\nu}u^\beta_r)(q^{j\gamma}_sCl^k_t)W^I_{\mu\nu}$
$Q^{(2)}_{lqudW}$	$\epsilon_{\alpha\beta\gamma}(\epsilon\tau^I)_{jk}(d^\alpha_pCu^\beta_r)(q^{j\gamma}_sC\sigma^{\mu\nu}l^k_t)W^I_{\mu\nu}$
$Q^{(1)}_{lqudB}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(d^\alpha_pC\sigma^{\mu\nu}u^\beta_r)(q^{j\gamma}_sCl^k_t)B_{\mu\nu}$
$Q^{(2)}_{lqudB}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(d^\alpha_pCu^\beta_r)(q^{j\gamma}_sC\sigma^{\mu\nu}l^k_t)B_{\mu\nu}$
$Q^{(1)}_{eq^2uG}$	$(T^A)^\delta_\gamma\epsilon_{\delta\alpha\beta}\epsilon_{jk}(q^{j\alpha}_pC\sigma^{\mu\nu}q^{k\beta}_r)(u^\gamma_sCe_t)G^A_{\mu\nu}$
$Q^{(2)}_{eq^2uG}$	$(T^A)^\delta_{(\alpha}\epsilon_{\beta)\gamma\delta}\epsilon_{jk}(q^{j\alpha}_pCq^{k\beta}_r)(u^\gamma_sC\sigma^{\mu\nu}e_t)G^A_{\mu\nu}$
$Q^{(1)}_{eq^2uW}$	$\epsilon_{\alpha\beta\gamma}(\epsilon\tau^I)_{jk}(q^{j\alpha}_pC\sigma^{\mu\nu}q^{k\beta}_r)(u^\gamma_sCe_t)W^I_{\mu\nu}$
$Q^{(1)}_{eq^2uB}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(q^{j\alpha}_pCq^{k\beta}_r)(u^\gamma_sC\sigma^{\mu\nu}e_t)B_{\mu\nu}$
$Q^{(1)}_{lq^3G}$	$(T^A)^\delta_\gamma\epsilon_{\delta\alpha\beta}\epsilon_{mn}\epsilon_{jk}(q^{m\alpha}_pC\sigma^{\mu\nu}q^{j\beta}_r)(q^{k\gamma}_sCl^n_t)G^A_{\mu\nu}$
$Q^{(2)}_{lq^3G}$	$(T^A)^\delta_{(\alpha}\epsilon_{\beta)\gamma\delta}\epsilon_{mn}\epsilon_{jk}(q^{m\alpha}_pCq^{j\beta}_r)(q^{k\gamma}_sC\sigma^{\mu\nu}l^n_t)G^A_{\mu\nu}$
$Q^{(1)}_{lq^3W}$	$\epsilon_{\alpha\beta\gamma}(\epsilon\tau^I)_{mn}\epsilon_{jk}(q^{m\alpha}_pCq^{j\beta}_r)(q^{k\gamma}_sC\sigma^{\mu\nu}l^n_t)W^I_{\mu\nu}$
$Q^{(2)}_{lq^3W}$	$\epsilon_{\alpha\beta\gamma}(\epsilon\tau^I)_{mj}\epsilon_{kn}(q^{m\alpha}_pC\sigma^{\mu\nu}q^{j\beta}_r)(q^{k\gamma}_sCl^n_t)W^I_{\mu\nu}$
$Q^{(1)}_{lq^3B}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{mn}\epsilon_{jk}(q^{m\alpha}_pCq^{j\beta}_r)(q^{k\gamma}_sC\sigma^{\mu\nu}l^n_t)B_{\mu\nu}$
$Q^{(1)}_{eu^2dG}$	$(T^A)^\delta_\gamma\epsilon_{\delta\alpha\beta}(d^\alpha_pC\sigma^{\mu\nu}u^\beta_r)(u^\gamma_sCe_t)G^A_{\mu\nu}$
$Q^{(2)}_{eu^2dG}$	$(T^A)^\delta_\gamma\epsilon_{\delta\alpha\beta}(u^\alpha_pC\sigma^{\mu\nu}u^\beta_r)(d^\gamma_sCe_t)G^A_{\mu\nu}$
$Q^{(3)}_{eu^2dG}$	$(T^A)^\delta_{(\alpha}\epsilon_{\beta)\gamma\delta}(u^\alpha_pCu^\beta_r)(d^\gamma_sC\sigma^{\mu\nu}e_t)G^A_{\mu\nu}$
$Q^{(1)}_{eu^2dB}$	$\epsilon_{\alpha\beta\gamma}(d^\alpha_pC\sigma^{\mu\nu}u^\beta_r)(u^\gamma_sCe_t)B_{\mu\nu}$
$Q^{(2)}_{eu^2dB}$	$\epsilon_{\alpha\beta\gamma}(u^\alpha_pC\sigma^{\mu\nu}u^\beta_r)(d^\gamma_sCe_t)B_{\mu\nu}$
$Q^{(2)}_{eq^2uW}$	$\epsilon_{\alpha\beta\gamma}(\epsilon\tau^I)_{jk}(q^{j\alpha}_pCq^{k\beta}_r)(u^\gamma_sC\sigma^{\mu\nu}e_t)W^I_{\mu\nu}$
$Q^{(2)}_{eq^2uB}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(q^{j\alpha}_pC\sigma^{\mu\nu}q^{k\beta}_r)(u^\gamma_sCe_t)B_{\mu\nu}$
$Q^{(3)}_{lq^3G}$	$(T^A)^\delta_{(\alpha}\epsilon_{\beta)\gamma\delta}\epsilon_{mn}\epsilon_{jk}(q^{m\alpha}_pC\sigma^{\mu\nu}q^{j\beta}_r)(q^{k\gamma}_sCl^n_t)G^A_{\mu\nu}$
$Q^{(4)}_{lq^3G}$	$(T^A)^\delta_\gamma\epsilon_{\delta\alpha\beta}\epsilon_{mn}\epsilon_{jk}(q^{m\alpha}_pCq^{j\beta}_r)(q^{k\gamma}_sC\sigma^{\mu\nu}l^n_t)G^A_{\mu\nu}$
$Q^{(3)}_{lq^3W}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{mn}(\epsilon\tau^I)_{jk}(q^{m\alpha}_pCq^{j\beta}_r)(q^{k\gamma}_sC\sigma^{\mu\nu}l^n_t)W^I_{\mu\nu}$
$Q^{(2)}_{lq^3B}$	$\epsilon_{\alpha\beta\gamma}\epsilon_{mn}\epsilon_{jk}(q^{m\alpha}_pC\sigma^{\mu\nu}q^{j\beta}_r)(q^{k\gamma}_sCl^n_t)B_{\mu\nu}$

Murphy 2206.07722
see also: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008

SMEFT at $d=8$: Murphy basis

$20:\psi^4 HD+\text{h.c.}$	
$Q^{(1)}_{l^3eHD}$	$i(\bar l_p\gamma^\mu l_r)[(\bar l_s e_t)D_\mu H]$
$Q^{(2)}_{l^3eHD}$	$i(\bar l_p\gamma^\mu\tau^I l_r)[(\bar l_s e_t)\tau^I D_\mu H]$
$Q^{(3)}_{l^3eHD}$	$i(\bar l_p\gamma^\mu l_r)[(D_\mu\bar l_s e_t)H]$
$Q^{(1)}_{le^3HD}$	$i(\bar e_p\gamma^\mu e_r)[(\bar l_s D_\mu e_t)H]$
$Q^{(1)}_{leq^2HD}$	$i(\bar q_p\gamma^\mu q_r)[(\bar l_s e_t)D_\mu H]$
$Q^{(2)}_{leq^2HD}$	$i(\bar l_p\gamma^\mu q^\alpha_r)[(\bar q_{s\alpha} e_t)D_\mu H]$
$Q^{(3)}_{leq^2HD}$	$i(\bar q_p\gamma^\mu\tau^I q_r)[(\bar l_s e_t)\tau^I D_\mu H]$
$Q^{(4)}_{leq^2HD}$	$i(\bar l_p\gamma^\mu\tau^I q^\alpha_r)[(\bar q_{s\alpha} e_t)\tau^I D_\mu H]$
$Q^{(5)}_{leq^2HD}$	$i(\bar q_p\gamma^\mu q_r)[(\bar l_s D_\mu e_t)H]$
$Q^{(6)}_{leq^2HD}$	$i(\bar q_p\gamma^\nu\tau^I q_r)[(\bar l_s D_\mu e_t)\tau^I H]$
$Q^{(1)}_{leu^2HD}$	$i(\bar u_p\gamma^\mu u_r)[(\bar l_s e_t)D_\mu H]$
$Q^{(2)}_{leu^2HD}$	$i(\bar u_{p\alpha}\gamma^\mu e_r)[(\bar l_s u^\alpha_t)D_\mu H]$
$Q^{(3)}_{leu^2HD}$	$i(\bar u_p\gamma^\mu u_r)[(D_\mu\bar l_s e_t)H]$
$Q^{(1)}_{led^2HD}$	$i(\bar d_p\gamma^\mu d_r)[(\bar l_s e_t)D_\mu H]$
$Q^{(2)}_{led^2HD}$	$i(\bar d_{p\alpha}\gamma^\mu e_r)[(\bar l_s d^\alpha_t)D_\mu H]$
$Q^{(3)}_{led^2HD}$	$i(\bar d_p\gamma^\mu d_r)[(D_\mu\bar l_s e_t)H]$
$Q^{(1)}_{leudHD}$	$i\epsilon_{jk}(\bar u_p\gamma^\mu d_r)(\bar e_s l^j_t)D_\mu H^k$
$Q^{(2)}_{leudHD}$	$i\epsilon_{jk}(\bar e_p\gamma^\mu d^\alpha_r)(\bar u_{s\alpha} l^j_t)D_\mu H^k$
$Q^{(3)}_{leudHD}$	$i\epsilon_{jk}(\bar u_p\gamma^\mu d_r)(\bar e_s D_\mu l^j_t)H^k$
$Q^{(2)}_{le^3HD}$	$i(\bar e_p\gamma^\mu e_r)[(\bar l_s e_t)D_\mu H]$

$20:\psi^4 HD+\text{h.c.}$	
$Q^{(1)}_{l^2quHD}$	$i(\bar l_p\gamma^\mu l_r)[(\bar q_s u_t)D_\mu\widetilde H]$
$Q^{(2)}_{l^2quHD}$	$i(\bar q_{p\alpha}\gamma^\mu l_r)[(\bar l_s u^\alpha_t)D_\mu\widetilde H]$
$Q^{(3)}_{l^2quHD}$	$i(\bar l_p\gamma^\mu\tau^I l_r)[(\bar q_s u_t)\tau^I D_\mu\widetilde H]$
$Q^{(4)}_{l^2quHD}$	$i(\bar q_{p\alpha}\gamma^\mu\tau^I l_r)[(\bar l_s u^\alpha_t)\tau^I D_\mu\widetilde H]$
$Q^{(5)}_{l^2quHD}$	$i(\bar l_p\gamma^\mu l_r)[(\bar q_s D_\mu u_t)\widetilde H]$
$Q^{(6)}_{l^2quHD}$	$i(\bar l_p\gamma^\mu\tau^I l_r)[(\bar q_s D_\mu u_t)\tau^I\widetilde H]$
$Q^{(1)}_{e^2quHD}$	$i(\bar e_p\gamma^\mu e_r)[(\bar q_s u_t)D_\mu\widetilde H]$
$Q^{(2)}_{e^2quHD}$	$i(\bar e_p\gamma^\mu u^\alpha_r)[(\bar q_{s\alpha} e_t)D_\mu\widetilde H]$
$Q^{(3)}_{e^2quHD}$	$i(\bar e_p\gamma^\mu e_r)[(D_\mu\bar q_s u_t)\widetilde H]$
$Q^{(1)}_{q^3uHD}$	$i(\bar q_p\gamma^\mu q_r)[(\bar q_s u_t)D_\mu\widetilde H]$
$Q^{(2)}_{q^3uHD}$	$i(\bar q_p\gamma^\mu\tau^I q_r)[(\bar q_s u_t)\tau^I D_\mu\widetilde H]$
$Q^{(3)}_{q^3uHD}$	$i(\bar q_p\gamma^\mu T^A q_r)[(\bar q_s T^A u_t)D_\mu\widetilde H]$
$Q^{(4)}_{q^3uHD}$	$i(\bar q_p\gamma^\mu T^A\tau^I q_r)[(\bar q_s T^A u_t)\tau^I D_\mu\widetilde H]$
$Q^{(5)}_{q^3uHD}$	$i(\bar q_p\gamma^\mu q_r)[(D_\mu\bar q_s u_t)\widetilde H]$
$Q^{(6)}_{q^3uHD}$	$i(\bar q_p\gamma^\mu\tau^I q_r)[(D_\mu\bar q_s u_t)\tau^I\widetilde H]$
$Q^{(1)}_{qu^3HD}$	$i(\bar u_p\gamma^\mu u_r)[(\bar q_s u_t)D_\mu\widetilde H]$
$Q^{(2)}_{qu^3HD}$	$i(\bar u_p\gamma^\mu T^A u_r)[(\bar q_s T^A u_t)D_\mu\widetilde H]$
$Q^{(3)}_{qu^3HD}$	$i(\bar u_p\gamma^\mu u_r)[(\bar q_s D_\mu u_t)\widetilde H]$
$Q^{(1)}_{qud^2HD}$	$i(\bar d_p\gamma^\mu d_r)[(\bar q_s u_t)D_\mu\widetilde H]$
$Q^{(2)}_{qud^2HD}$	$i(\bar d_p\gamma^\mu u_r)[(\bar q_s d_t)D_\mu\widetilde H]$
$Q^{(3)}_{qud^2HD}$	$i(\bar d_p\gamma^\mu T^A d_r)[(\bar q_s T^A u_t)D_\mu\widetilde H]$
$Q^{(4)}_{qud^2HD}$	$i(\bar d_p\gamma^\mu T^A u_r)[(\bar q_s T^A d_t)D_\mu\widetilde H]$
$Q^{(5)}_{qud^2HD}$	$i(\bar d_p\gamma^\mu d_r)[(D_\mu\bar q_s u_t)\widetilde H]$
$Q^{(6)}_{qud^2HD}$	$i(\bar d_p\gamma^\mu T^A d_r)[(D_\mu\bar q_s T^A u_t)\widetilde H]$

$20:\psi^4 HD+\text{h.c.}$	
$Q^{(1)}_{l^2qdHD}$	$i(\bar l_p\gamma^\mu l_r)[(\bar q_s d_t)D_\mu H]$
$Q^{(2)}_{l^2qdHD}$	$i(\bar q_{p\alpha}\gamma^\mu l_r)[(\bar l_s d^\alpha_t)D_\mu H]$
$Q^{(3)}_{l^2qdHD}$	$i(\bar l_p\gamma^\mu\tau^I l_r)[(\bar q_s d_t)\tau^I D_\mu H]$
$Q^{(4)}_{l^2qdHD}$	$i(\bar q_{p\alpha}\gamma^\mu\tau^I l_r)[(\bar l_s d^\alpha_t)\tau^I D_\mu H]$
$Q^{(5)}_{l^2qdHD}$	$i(\bar l_p\gamma^\mu l_r)[(\bar q_s D_\mu d_t)H]$
$Q^{(6)}_{l^2qdHD}$	$i(\bar l_p\gamma^\mu\tau^I l_r)[(\bar q_s D_\mu d_t)\tau^I H]$
$Q^{(1)}_{e^2qdHD}$	$i(\bar e_p\gamma^\mu e_r)[(\bar q_s d_t)D_\mu H]$
$Q^{(2)}_{e^2qdHD}$	$i(\bar e_p\gamma^\mu d^\alpha_r)[(\bar q_{s\alpha} e_t)D_\mu H]$
$Q^{(3)}_{e^2qdHD}$	$i(\bar e_p\gamma^\mu e_r)[(D_\mu\bar q_s d_t)H]$
$Q^{(1)}_{q^3dHD}$	$i(\bar q_p\gamma^\mu q_r)[(\bar q_s d_t)D_\mu H]$
$Q^{(2)}_{q^3dHD}$	$i(\bar q_p\gamma^\mu\tau^I q_r)[(\bar q_s d_t)\tau^I D_\mu H]$
$Q^{(3)}_{q^3dHD}$	$i(\bar q_p\gamma^\mu T^A q_r)[(\bar q_s T^A d_t)D_\mu H]$
$Q^{(4)}_{q^3dHD}$	$i(\bar q_p\gamma^\mu T^A\tau^I q_r)[(\bar q_s T^A d_t)\tau^I D_\mu H]$
$Q^{(5)}_{q^3dHD}$	$i(\bar q_p\gamma^\mu q_r)[(D_\mu\bar q_s d_t)H]$
$Q^{(6)}_{q^3dHD}$	$i(\bar q_p\gamma^\mu\tau^I q_r)[(D_\mu\bar q_s d_t)\tau^I H]$
$Q^{(1)}_{qu^2dHD}$	$i(\bar u_p\gamma^\mu u_r)[(\bar q_s d_t)D_\mu H]$
$Q^{(2)}_{qu^2dHD}$	$i(\bar u_p\gamma^\mu d_r)[(\bar q_s u_t)D_\mu H]$
$Q^{(3)}_{qu^2dHD}$	$i(\bar u_p\gamma^\mu T^A u_r)[(\bar q_s T^A d_t)D_\mu H]$
$Q^{(4)}_{qu^2dHD}$	$i(\bar u_p\gamma^\mu T^A d_r)[(\bar q_s T^A u_t)D_\mu H]$
$Q^{(5)}_{qu^2dHD}$	$i(\bar u_p\gamma^\mu u_r)[(D_\mu\bar q_s d_t)H]$
$Q^{(6)}_{qu^2dHD}$	$i(\bar u_p\gamma^\mu T^A u_r)[(D_\mu\bar q_s T^A d_t)H]$
$Q^{(1)}_{qd^3HD}$	$i(\bar d_p\gamma^\mu d_r)[(\bar q_s d_t)D_\mu H]$
$Q^{(2)}_{qd^3HD}$	$i(\bar d_p\gamma^\mu T^A d_r)[(\bar q_s T^A d_t)D_\mu H]$
$Q^{(3)}_{qd^3HD}$	$i(\bar d_p\gamma^\mu d_r)[(\bar q_s D_\mu d_t)H]$

$20(\not B):\psi^4 HD+\text{h.c.}$	
$Q^{(1)}_{lu^2dHD}$	$i\epsilon_{\alpha\beta\gamma}[D_\mu H^\dagger(u^\alpha_p C\gamma^\mu l_r)](u^\beta_s C d^\gamma_t)$
$Q^{(2)}_{lu^2dHD}$	$i\epsilon_{\alpha\beta\gamma}[H^\dagger(u^\alpha_p C\gamma^\mu l_r)](D_\mu u^\beta_s C d^\gamma_t)$
$Q^{(1)}_{lud^2HD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(d^\alpha_p C\gamma^\mu l^j_r)(d^\beta_s C u^\gamma_t)D_\mu H^k$
$Q^{(2)}_{lud^2HD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(d^\alpha_p C\gamma^\mu l^j_r)(D_\mu d^\beta_s C u^\gamma_t)H^k$
$Q^{(1)}_{lq^2uHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jn}\epsilon_{km}D_\mu H^{n\dagger}(q^{m\alpha}_p C\gamma^\mu u^\beta_r)(q^{j\gamma}_s C l^k_t)$
$Q^{(2)}_{lq^2uHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{kn}\epsilon_{jm}D_\mu H^{n\dagger}(q^{m\alpha}_p C\gamma^\mu u^\beta_r)(q^{j\gamma}_s C l^k_t)$
$Q^{(3)}_{lq^2uHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jn}\epsilon_{km}H^{n\dagger}(q^{m\alpha}_p C\gamma^\mu u^\beta_r)(D_\mu q^{j\gamma}_s C l^k_t)$
$Q^{(1)}_{lq^2dHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jn}\epsilon_{km}(q^{m\alpha}_p C\gamma^\mu d^\beta_r)(q^{j\gamma}_s C l^k_t)D_\mu H^n$
$Q^{(2)}_{lq^2dHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{kn}\epsilon_{jm}(q^{m\alpha}_p C\gamma^\mu d^\beta_r)(q^{j\gamma}_s C l^k_t)D_\mu H^n$
$Q^{(3)}_{lq^2dHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jn}\epsilon_{km}(q^{m\alpha}_p C\gamma^\mu d^\beta_r)(D_\mu q^{j\gamma}_s C l^k_t)H^n$
Q_{eq^3HD}	$i\epsilon_{\alpha\beta\gamma}\epsilon_{mn}\epsilon_{jk}(q^{j\alpha}_p C\gamma^\mu e_r)(D_\mu q^{k\beta}_s C q^{m\gamma}_t)H^n$
$Q^{(1)}_{equ^2HD}$	$i\epsilon_{\alpha\beta\gamma}[D_\mu H^\dagger(u^\alpha_p C\gamma^\mu q^\beta_r)](u^\gamma_s C e_t)$
$Q^{(2)}_{equ^2HD}$	$i\epsilon_{\alpha\beta\gamma}[H^\dagger(u^\alpha_p C\gamma^\mu q^\beta_r)](D_\mu u^\gamma_s C e_t)$
$Q^{(1)}_{equdHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(q^{j\alpha}_p C\gamma^\mu u^\beta_r)(d^\gamma_s C e_t)D_\mu H^k$
$Q^{(2)}_{equdHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(q^{j\alpha}_p C\gamma^\mu d^\beta_r)(u^\gamma_s C e_t)D_\mu H^k$
$Q^{(3)}_{equdHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(q^{j\alpha}_p C\gamma^\mu u^\beta_r)(d^\gamma_s C D_\mu e_t)H^k$

Murphy 2206.07722
see also: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008

SMEFT at $d = 8$: Murphy basis

Murphy 2206.07722
see also: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008

21 : $(\bar{L}L)(\bar{L}L)D^2$

$Q^{(1)}_{l^4D^2}$	$D^\nu(\bar{l}_p\gamma^\mu l_r)D_\nu(\bar{l}_s\gamma_\mu l_t)$
$Q^{(2)}_{l^4D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)(\bar{l}_s\gamma_\mu \overleftrightarrow{D}_\nu l_t)$
$Q^{(1)}_{q^4D^2}$	$D^\nu(\bar{q}_p\gamma^\mu q_r)D_\nu(\bar{q}_s\gamma_\mu q_t)$
$Q^{(2)}_{q^4D^2}$	$(\bar{q}_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)(\bar{q}_s\gamma_\mu \overleftrightarrow{D}_\nu q_t)$
$Q^{(3)}_{q^4D^2}$	$D^\nu(\bar{q}_p\gamma^\mu\tau^I q_r)D_\nu(\bar{q}_s\gamma_\mu\tau^I q_t)$
$Q^{(4)}_{q^4D^2}$	$(\bar{q}_p\gamma^\mu \overleftrightarrow{D}^{I\nu} q_r)(\bar{q}_s\gamma_\mu \overleftrightarrow{D}^I_\nu q_t)$
$Q^{(1)}_{l^2q^2D^2}$	$D^\nu(\bar{l}_p\gamma^\mu l_r)D_\nu(\bar{q}_s\gamma_\mu q_t)$
$Q^{(2)}_{l^2q^2D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)(\bar{q}_s\gamma_\mu \overleftrightarrow{D}_\nu q_t)$
$Q^{(3)}_{l^2q^2D^2}$	$D^\nu(\bar{l}_p\gamma^\mu\tau^I l_r)D_\nu(\bar{q}_s\gamma_\mu\tau^I q_t)$
$Q^{(4)}_{l^2q^2D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^{I\nu} l_r)(\bar{q}_s\gamma_\mu \overleftrightarrow{D}^I_\nu q_t)$

21 : $(\bar{R}R)(\bar{R}R)D^2$

$Q_{e^4D^2}$	$D^\nu(\bar{e}_p\gamma^\mu e_r)D_\nu(\bar{e}_s\gamma_\mu e_t)$
$Q^{(1)}_{u^4D^2}$	$D^\nu(\bar{u}_p\gamma^\mu u_r)D_\nu(\bar{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{u^4D^2}$	$(\bar{u}_p\gamma^\mu \overleftrightarrow{D}^\nu u_r)(\bar{u}_s\gamma_\mu \overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{d^4D^2}$	$D^\nu(\bar{d}_p\gamma^\mu d_r)D_\nu(\bar{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{d^4D^2}$	$(\bar{d}_p\gamma^\mu \overleftrightarrow{D}^\nu d_r)(\bar{d}_s\gamma_\mu \overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{e^2u^2D^2}$	$D^\nu(\bar{e}_p\gamma^\mu e_r)D_\nu(\bar{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{e^2u^2D^2}$	$(\bar{e}_p\gamma^\mu \overleftrightarrow{D}^\nu e_r)(\bar{u}_s\gamma_\mu \overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{e^2d^2D^2}$	$D^\nu(\bar{e}_p\gamma^\mu e_r)D_\nu(\bar{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{e^2d^2D^2}$	$(\bar{e}_p\gamma^\mu \overleftrightarrow{D}^\nu e_r)(\bar{d}_s\gamma_\mu \overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{u^2d^2D^2}$	$D^\nu(\bar{u}_p\gamma^\mu u_r)D_\nu(\bar{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{u^2d^2D^2}$	$(\bar{u}_p\gamma^\mu \overleftrightarrow{D}^\nu u_r)(\bar{d}_s\gamma_\mu \overleftrightarrow{D}_\nu d_t)$
$Q^{(3)}_{u^2d^2D^2}$	$D^\nu(\bar{u}_p\gamma^\mu T^A u_r)D_\nu(\bar{d}_s\gamma_\mu T^A d_t)$
$Q^{(4)}_{u^2d^2D^2}$	$(\bar{u}_p\gamma^\mu T^A \overleftrightarrow{D}^\nu u_r)(\bar{d}_s\gamma_\mu T^A \overleftrightarrow{D}_\nu d_t)$

21 : $(\bar{L}L)(\bar{R}R)D^2$

$Q^{(1)}_{l^2e^2D^2}$	$D^\nu(\bar{l}_p\gamma^\mu l_r)D_\nu(\bar{e}_s\gamma_\mu e_t)$
$Q^{(2)}_{l^2e^2D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)(\bar{e}_s\gamma_\mu \overleftrightarrow{D}_\nu e_t)$
$Q^{(1)}_{l^2u^2D^2}$	$D^\nu(\bar{l}_p\gamma^\mu l_r)D_\nu(\bar{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{l^2u^2D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)(\bar{u}_s\gamma_\mu \overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{l^2d^2D^2}$	$D^\nu(\bar{l}_p\gamma^\mu l_r)D_\nu(\bar{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{l^2d^2D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)(\bar{d}_s\gamma_\mu \overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{q^2e^2D^2}$	$D^\nu(\bar{q}_p\gamma^\mu q_r)D_\nu(\bar{e}_s\gamma_\mu e_t)$
$Q^{(2)}_{q^2e^2D^2}$	$(\bar{q}_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)(\bar{e}_s\gamma_\mu \overleftrightarrow{D}_\nu e_t)$
$Q^{(1)}_{q^2u^2D^2}$	$D^\nu(\bar{q}_p\gamma^\mu q_r)D_\nu(\bar{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{q^2u^2D^2}$	$(\bar{q}_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)(\bar{u}_s\gamma_\mu \overleftrightarrow{D}_\nu u_t)$
$Q^{(3)}_{q^2u^2D^2}$	$D^\nu(\bar{q}_p\gamma^\mu T^A q_r)D_\nu(\bar{u}_s\gamma_\mu T^A u_t)$
$Q^{(4)}_{q^2u^2D^2}$	$(\bar{q}_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)(\bar{u}_s\gamma_\mu T^A \overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{q^2d^2D^2}$	$D^\nu(\bar{q}_p\gamma^\mu q_r)D_\nu(\bar{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{q^2d^2D^2}$	$(\bar{q}_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)(\bar{d}_s\gamma_\mu \overleftrightarrow{D}_\nu d_t)$
$Q^{(3)}_{q^2d^2D^2}$	$D^\nu(\bar{q}_p\gamma^\mu T^A q_r)D_\nu(\bar{d}_s\gamma_\mu T^A d_t)$
$Q^{(4)}_{q^2d^2D^2}$	$(\bar{q}_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)(\bar{d}_s\gamma_\mu T^A \overleftrightarrow{D}_\nu d_t)$

21 : $(\bar{L}R)(\bar{L}R)D^2$ + h.c.

$Q^{(1)}_{q^2udD^2}$	$D_\mu(\bar{q}^j_p u_r)\epsilon_{jk}D^\mu(\bar{q}^k_s d_t)$
$Q^{(2)}_{q^2udD^2}$	$D_\mu(\bar{q}^j_p T^A u_r)\epsilon_{jk}D^\mu(\bar{q}^k_s T^A d_t)$
$Q^{(3)}_{q^2udD^2}$	$(\bar{q}^j_p \overleftrightarrow{D}^\mu u_r)\epsilon_{jk}(\bar{q}^k_s \overleftrightarrow{D}_\mu d_t)$
$Q^{(1)}_{lequD^2}$	$D_\mu(\bar{l}^j_p e_r)\epsilon_{jk}D^\mu(\bar{q}^k_s u_t)$
$Q^{(2)}_{lequD^2}$	$D_\mu(\bar{l}^j_p u^\alpha_r)\epsilon_{jk}D^\mu(\bar{q}^k_{s\alpha} e_t)$
$Q^{(3)}_{lequD^2}$	$(\bar{l}^j_p \overleftrightarrow{D}^\mu e_r)\epsilon_{jk}(\bar{q}^k_s \overleftrightarrow{D}_\mu u_t)$

SMEFT at $d = 8$: Murphy basis

$21 : (\bar{L}L)(\bar{L}L)D^2$

$Q^{(1)}_{l^4D^2}$	$D^\nu(\bar{l}_p\gamma^\mu l_r)D_\nu(\bar{l}_s\gamma_\mu l_t)$
$Q^{(2)}_{l^4D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)(\bar{l}_s\gamma_\mu \overleftrightarrow{D}_\nu l_t)$
$Q^{(1)}_{q^4D^2}$	$D^\nu(\bar{q}_p\gamma^\mu q_r)D_\nu(\bar{q}_s\gamma_\mu q_t)$
$Q^{(2)}_{q^4D^2}$	$(\bar{q}_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)(\bar{q}_s\gamma_\mu \overleftrightarrow{D}_\nu q_t)$
$Q^{(3)}_{q^4D^2}$	$D^\nu(\bar{q}_p\gamma^\mu\tau^I q_r)D_\nu(\bar{q}_s\gamma_\mu\tau^I q_t)$
$Q^{(4)}_{q^4D^2}$	$(\bar{q}_p\gamma^\mu \overleftrightarrow{D}^{I\nu} q_r)(\bar{q}_s\gamma_\mu \overleftrightarrow{D}^I_\nu q_t)$
$Q^{(1)}_{l^2q^2D^2}$	$D^\nu(\bar{l}_p\gamma^\mu l_r)D_\nu(\bar{q}_s\gamma_\mu q_t)$
$Q^{(2)}_{l^2q^2D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)(\bar{q}_s\gamma_\mu \overleftrightarrow{D}_\nu q_t)$
$Q^{(3)}_{l^2q^2D^2}$	$D^\nu(\bar{l}_p\gamma^\mu\tau^I l_r)D_\nu(\bar{q}_s\gamma_\mu\tau^I q_t)$
$Q^{(4)}_{l^2q^2D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^{I\nu} l_r)(\bar{q}_s\gamma_\mu \overleftrightarrow{D}^I_\nu q_t)$

$21 : (\bar{R}R)(\bar{R}R)D^2$

$Q_{e^4D^2}$	$D^\nu(\bar{e}_p\gamma^\mu e_r)D_\nu(\bar{e}_s\gamma_\mu e_t)$
$Q^{(1)}_{u^4D^2}$	$D^\nu(\bar{u}_p\gamma^\mu u_r)D_\nu(\bar{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{u^4D^2}$	$(\bar{u}_p\gamma^\mu \overleftrightarrow{D}^\nu u_r)(\bar{u}_s\gamma_\mu \overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{d^4D^2}$	$D^\nu(\bar{d}_p\gamma^\mu d_r)D_\nu(\bar{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{d^4D^2}$	$(\bar{d}_p\gamma^\mu \overleftrightarrow{D}^\nu d_r)(\bar{d}_s\gamma_\mu \overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{e^2u^2D^2}$	$D^\nu(\bar{e}_p\gamma^\mu e_r)D_\nu(\bar{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{e^2u^2D^2}$	$(\bar{e}_p\gamma^\mu \overleftrightarrow{D}^\nu e_r)(\bar{u}_s\gamma_\mu \overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{e^2d^2D^2}$	$D^\nu(\bar{e}_p\gamma^\mu e_r)D_\nu(\bar{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{e^2d^2D^2}$	$(\bar{e}_p\gamma^\mu \overleftrightarrow{D}^\nu e_r)(\bar{d}_s\gamma_\mu \overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{u^2d^2D^2}$	$D^\nu(\bar{u}_p\gamma^\mu u_r)D_\nu(\bar{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{u^2d^2D^2}$	$(\bar{u}_p\gamma^\mu \overleftrightarrow{D}^\nu u_r)(\bar{d}_s\gamma_\mu \overleftrightarrow{D}_\nu d_t)$
$Q^{(3)}_{u^2d^2D^2}$	$D^\nu(\bar{u}_p\gamma^\mu T^A u_r)D_\nu(\bar{d}_s\gamma_\mu T^A d_t)$
$Q^{(4)}_{u^2d^2D^2}$	$(\bar{u}_p\gamma^\mu T^A \overleftrightarrow{D}^\nu u_r)(\bar{d}_s\gamma_\mu T^A \overleftrightarrow{D}_\nu d_t)$

$21 : (\bar{L}L)(\bar{R}R)D^2$

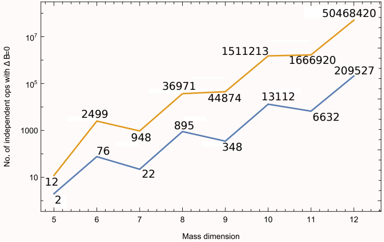
$Q^{(1)}_{l^2e^2D^2}$	$D^\nu(\bar{l}_p\gamma^\mu l_r)D_\nu(\bar{e}_s\gamma_\mu e_t)$
$Q^{(2)}_{l^2e^2D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)(\bar{e}_s\gamma_\mu \overleftrightarrow{D}_\nu e_t)$
$Q^{(1)}_{l^2u^2D^2}$	$D^\nu(\bar{l}_p\gamma^\mu l_r)D_\nu(\bar{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{l^2u^2D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)(\bar{u}_s\gamma_\mu \overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{l^2d^2D^2}$	$D^\nu(\bar{l}_p\gamma^\mu l_r)D_\nu(\bar{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{l^2d^2D^2}$	$(\bar{l}_p\gamma^\mu \overleftrightarrow{D}^\nu l_r)(\bar{d}_s\gamma_\mu \overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{q^2e^2D^2}$	$D^\nu(\bar{q}_p\gamma^\mu q_r)D_\nu(\bar{e}_s\gamma_\mu e_t)$
$Q^{(2)}_{q^2e^2D^2}$	$(\bar{q}_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)(\bar{e}_s\gamma_\mu \overleftrightarrow{D}_\nu e_t)$
$Q^{(1)}_{q^2u^2D^2}$	$D^\nu(\bar{q}_p\gamma^\mu q_r)D_\nu(\bar{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{q^2u^2D^2}$	$(\bar{q}_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)(\bar{u}_s\gamma_\mu \overleftrightarrow{D}_\nu u_t)$
$Q^{(3)}_{q^2u^2D^2}$	$D^\nu(\bar{q}_p\gamma^\mu T^A q_r)D_\nu(\bar{u}_s\gamma_\mu T^A u_t)$
$Q^{(4)}_{q^2u^2D^2}$	$(\bar{q}_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)(\bar{u}_s\gamma_\mu T^A \overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{q^2d^2D^2}$	$D^\nu(\bar{q}_p\gamma^\mu q_r)D_\nu(\bar{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{q^2d^2D^2}$	$(\bar{q}_p\gamma^\mu \overleftrightarrow{D}^\nu q_r)(\bar{d}_s\gamma_\mu \overleftrightarrow{D}_\nu d_t)$
$Q^{(3)}_{q^2d^2D^2}$	$D^\nu(\bar{q}_p\gamma^\mu T^A q_r)D_\nu(\bar{d}_s\gamma_\mu T^A d_t)$
$Q^{(4)}_{q^2d^2D^2}$	$(\bar{q}_p\gamma^\mu T^A \overleftrightarrow{D}^\nu q_r)(\bar{d}_s\gamma_\mu T^A \overleftrightarrow{D}_\nu d_t)$

$21 : (\bar{L}R)(\bar{L}R)D^2 + \text{h.c.}$

$Q^{(1)}_{q^2udD^2}$	$D_\mu(\bar{q}^j_p u_r)\epsilon_{jk}D^\mu(\bar{q}^k_s d_t)$
$Q^{(2)}_{q^2udD^2}$	$D_\mu(\bar{q}^j_p T^A u_r)\epsilon_{jk}D^\mu(\bar{q}^k_s T^A d_t)$
$Q^{(3)}_{q^2udD^2}$	$(\bar{q}^j_p \overleftrightarrow{D}^\mu u_r)\epsilon_{jk}(\bar{q}^k_s \overleftrightarrow{D}_\mu d_t)$
$Q^{(1)}_{lequD^2}$	$D_\mu(\bar{l}^j_p e_r)\epsilon_{jk}D^\mu(\bar{q}^k_s u_t)$
$Q^{(2)}_{lequD^2}$	$D_\mu(\bar{l}^j_p u^\alpha_r)\epsilon_{jk}D^\mu(\bar{q}^k_{s\alpha} e_t)$
$Q^{(3)}_{lequD^2}$	$(\bar{l}^j_p \overleftrightarrow{D}^\mu e_r)\epsilon_{jk}(\bar{q}^k_s \overleftrightarrow{D}_\mu u_t)$

Murphy 2206.07722
see also: Li,Ren,Shu,Xiao,Yu,Zheng 2005.00008

 # parameters computed with Hilbert series and automated Henning,Lu,Melia,Murayama 1512.03433



bases available up to dimension 12

d = 5 Weinberg PRL43(1979)1566

d = 6 Grzadkowski et al 1008.4884 ...

d = 7 Lehman 1410.4193, Henning et al 1512.0343

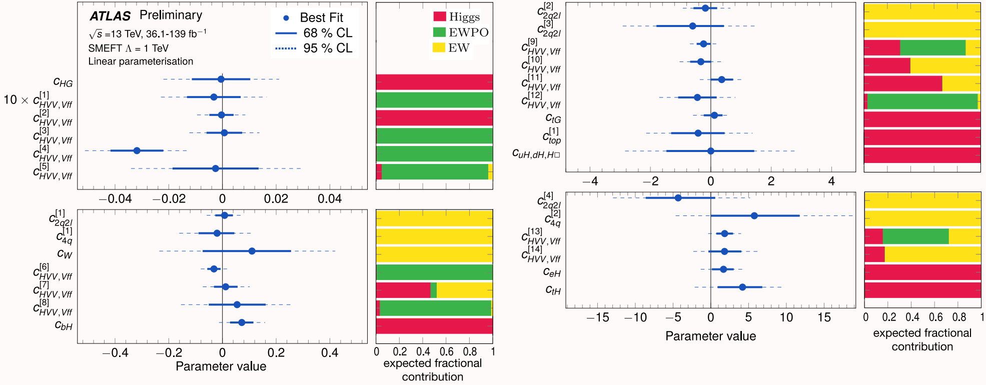
d = 8 Li et al 2005.00008, Murphy 2005.00059

d = 9 Li et al 2007.07899, Liao,Ma 2007.08125

d = 10,11,12 Harlander,Kempksens,Schaaf 2305.06832

The SMEFT program for the LHC

- a vast campaign of measurements in Higgs, EW, top, Drell-Yan and other processes
- most ambitious goal: large global analysis to **measure** as many Wilson coefficients as possible
- a large research program with big efforts in theory and experiment



ATL-PHYS-PUB-2022-037

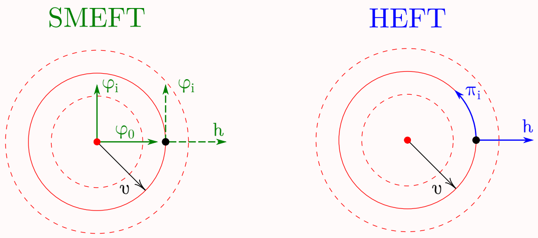
The Higgs Effective Field Theory – HEFT

rather than H doublet:
singlet h + Goldstones $\mathbf{U}$

Feruglio 9301281, Grinstein,Trott 0704.1505, Buchalla,Catà 1203.6510, Alonso et al 1212.3305, IB et al 1311.1823,1604.06801, Buchalla et al 1307.5017,1511.00988. . .

$$H \mapsto \frac{v + \boxed{h}}{\sqrt{2}}\,\boxed{\mathbf{U}}, \qquad \mathbf{U} = \exp\left(\frac{i\vec{\sigma}\cdot\vec{\pi}}{v}\right)$$

SMEFT expands around **EW-symmetric point**, HEFT expands around **EW vacuum**



HEFT notation basics

$$\begin{aligned}\mathscr{L}_{SM} = & -\frac{1}{4}\langle W_{\mu\nu}W^{\mu\nu}\rangle - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}G^a_{\mu\nu}G^{a\mu\nu} + \frac{1}{2}\partial_\mu h \partial^\mu h \\ & - \frac{v^2}{4}\langle \mathbf{V}_\mu \mathbf{V}^\mu\rangle \mathcal{F}(h) - \mathcal{V}(h) \\ & + i\bar{Q}_L \not{D} Q_L + i\bar{Q}_R \not{D} Q_R + i\bar{L}_L \not{D} L_L + i\bar{L}_R \not{D} L_R \\ & - \frac{v}{\sqrt{2}}\left[\bar{Q}_L \mathbf{U}\mathcal{Y}_Q(h) Q_R + \text{h.c.}\right] - \frac{v}{\sqrt{2}}\left[\bar{L}_L \mathbf{U}\mathcal{Y}_L(h) L_R + \text{h.c.}\right]\end{aligned}$$

$$\boxed{\mathbf{V}_\mu} = (D_\mu \mathbf{U})\mathbf{U}^\dagger \sim W_\mu, Z_\mu \qquad Q_{L,R} = \begin{pmatrix} u_{L,R} \\ d_{L,R} \end{pmatrix}, \quad L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, \quad L_R = \begin{pmatrix} 0 \\ e_R \end{pmatrix}$$

$\mathbf{T} = \mathbf{U}\sigma^3\mathbf{U}^\dagger$ (~~cust.~~ spurion)

$$\boxed{\mathcal{F}_i(h)} = 1 + a_i \frac{h}{v} + b_i \frac{h^2}{v^2} + \dots \qquad \langle \cdot \rangle = \underset{SU(2)}{\mathrm{Tr}}(\cdot)$$

Main HEFT features

- **more general** than SMEFT because implements weaker symmetry requirement
  there are UV scenarios that can be matched to HEFT but not SMEFT (more later)

  HEFT $\supset$ SMEFT $\supset$ SM

- in general **more convergent** than SMEFT: takes fewer orders to reproduce well UV model
  $\to$ classic example: composite Higgs

- **more complicated power counting**, mix of χPT and canonical dimensions

  Gavela,Jenkins,Manohar,Merlo 1601.07551
  Buchalla,Catà,(Celis),Krause 1312.5624,1603.03062

  orders are defined as $\mathscr{L}_{HEFT} = \mathscr{L}_0 + \boxed{\mathscr{L}_1} + \mathscr{L}_2 + \dots$

  $\boxed{\mathscr{L}_1}$ = leading deviations from SM = "4 derivatives" = NLO

- order-by-order, **more operators** than SMEFT

  for 3 flavors, L, B cons: $\mathscr{L}_1$: 6573, $\mathscr{L}_2$: 10^6+

  Hilbert series counting is available Gráf,Henning,Lu,Melia,Murayama 2211.06725

  complete bases available up to $\mathscr{L}_2$ Buchalla,Catà,Krause 1307.5017, IB et al 1604.06801
  Sun,Xiao,Yu 2210.14939, Sun,Wang,Yu 2211.11598

Example: HEFT bosonic basis in $\mathscr{L}_1$

39 operators (vs **15** in dim-6 Warsaw basis, **89** in dim-8 Murphy basis) Sun,Xiao,Yu 2206.07722

$\langle \mathbf{V}_\mu \mathbf{V}^\mu \rangle^2 \mathcal{F}(h)$	$\langle \mathbf{V}_\mu \mathbf{V}_\nu \rangle^2 \mathcal{F}(h)$	$\partial_\mu \partial_\nu \mathcal{F}(h) \partial^\mu \partial^\nu \mathcal{F}(h)$
$\langle \mathbf{T}\mathbf{V}_\mu \rangle \langle \mathbf{T}\mathbf{V}_\nu \rangle \langle \mathbf{V}^\mu \mathbf{V}^\nu \rangle \mathcal{F}(h)$	$\langle \mathbf{T}\mathbf{V}_\mu \rangle^2 \langle \mathbf{V}_\nu \mathbf{V}^\nu \rangle \mathcal{F}(h)$	$\langle \mathbf{T}\mathbf{V}_\mu \rangle^4 \mathcal{F}(h)$
$\langle \mathbf{T}\mathbf{V}_\mu \rangle \langle \mathbf{V}_\nu \mathbf{V}^\nu \rangle \partial^\mu \mathcal{F}(h)$	$\langle \mathbf{T}\mathbf{V}_\mu \rangle \langle \mathbf{V}^\mu \mathbf{V}^\nu \rangle \partial_\nu \mathcal{F}(h)$	$\langle \mathbf{T}\mathbf{V}_\mu \mathbf{V}_\nu \rangle \langle \mathbf{T}\mathbf{V}^\mu \rangle \partial^\nu \mathcal{F}(h)$
$\langle \mathbf{T}\mathbf{V}_\mu \rangle^2 \langle \mathbf{T}\mathbf{V}_\nu \rangle \partial^\nu \mathcal{F}(h)$	$\langle \mathbf{T}\mathbf{V}_\mu \rangle \langle \mathbf{T}\mathbf{V}_\nu \rangle \partial^\mu \partial^\nu \mathcal{F}(h)$	$\langle \mathbf{T}\mathbf{V}_\mu \rangle^2 \partial_\nu \mathcal{F}(h) \partial^\nu \mathcal{F}(h)$
$\langle \mathbf{V}_\mu \mathbf{V}_\nu \rangle \partial^\mu \partial^\nu \mathcal{F}(h)$	$\langle \mathbf{V}_\mu \mathbf{V}^\mu \rangle \partial^\nu \mathcal{F}(h) \partial_\nu \mathcal{F}(h)$	$\langle \mathbf{T}\mathbf{V}_\mu \rangle \partial_\nu \mathcal{F}(h) \partial^\mu \partial^\nu \mathcal{F}(h)$
$\langle \tilde{W}_{\mu\nu} \mathbf{V}^\mu \rangle \langle \mathbf{T}\mathbf{V}^\nu \rangle \mathcal{F}(h)$	$\langle \mathbf{T}[\tilde{W}_{\mu\nu}, \mathbf{V}^\nu] \rangle \langle \mathbf{T}\mathbf{V}^\mu \rangle \mathcal{F}(h)$	$\langle W_{\mu\nu} \mathbf{V}^\mu \rangle \langle \mathbf{T}\mathbf{V}^\nu \rangle \mathcal{F}(h)$
$\langle W_{\mu\nu} [\mathbf{V}^\mu, \mathbf{V}^\nu] \rangle \mathcal{F}(h)$	$B_{\mu\nu} \langle \mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu] \rangle \mathcal{F}(h)$	$\langle W_{\mu\nu} \mathbf{T} \rangle \langle \mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu] \rangle \mathcal{F}(h)$
$\langle \tilde{W}_{\mu\nu} [\mathbf{V}^\mu, \mathbf{V}^\nu] \rangle \mathcal{F}(h)$	$\tilde{B}_{\mu\nu} \langle \mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu] \rangle \mathcal{F}(h)$	$\langle W_{\mu\nu} \mathbf{T} \rangle \langle \tilde{W}^{\mu\nu} \mathbf{T} \rangle \mathcal{F}(h)$
$B_{\mu\nu} \langle W^{\mu\nu} \mathbf{T} \rangle \mathcal{F}(h)$	$\tilde{B}_{\mu\nu} \langle W^{\mu\nu} \mathbf{T} \rangle \mathcal{F}(h)$	$\langle W_{\mu\nu} \mathbf{T} \rangle^2 \mathcal{F}(h)$
$B_{\mu\nu} B^{\mu\nu} \mathcal{F}(h)$	$W_{\mu\nu} W^{\mu\nu} \mathcal{F}(h)$	$G_{\mu\nu} G^{\mu\nu} \mathcal{F}(h)$
$B_{\mu\nu} \tilde{B}^{\mu\nu} \mathcal{F}(h)$	$W_{\mu\nu} \tilde{W}^{\mu\nu} \mathcal{F}(h)$	$G_{\mu\nu} \tilde{G}^{\mu\nu} \mathcal{F}(h)$
$f_{abc} G^a_{\mu\nu} G^{b\nu\rho} G^{c\nu}_\rho \mathcal{F}(h)$	$\varepsilon_{ijk} W^i_{\mu\nu} W^{j\nu\rho} W^{k\nu}_\rho \mathcal{F}(h)$	$\varepsilon_{ijk} B_{\mu\nu} W^{i\nu\rho} W^{j\nu}_\rho \mathbf{T}^k \mathcal{F}(h)$
$f_{abc} \tilde{G}^a_{\mu\nu} G^{b\nu\rho} G^{c\nu}_\rho \mathcal{F}(h)$	$\varepsilon_{ijk} \tilde{W}^i_{\mu\nu} W^{j\nu\rho} W^{k\nu}_\rho \mathcal{F}(h)$	$\varepsilon_{ijk} \tilde{B}_{\mu\nu} W^{i\nu\rho} W^{j\nu}_\rho \mathbf{T}^k \mathcal{F}(h)$

order-by-order comparison

SMEFT $\mathscr{L}_6$ vs. HEFT $\mathscr{L}_1$

two main classes of differences:

- interactions that are **correlated in SMEFT** and **decorrelated in HEFT**
- interactions that appear at **a lower order in HEFT** compared to SMEFT

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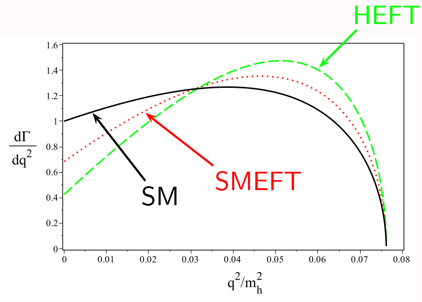
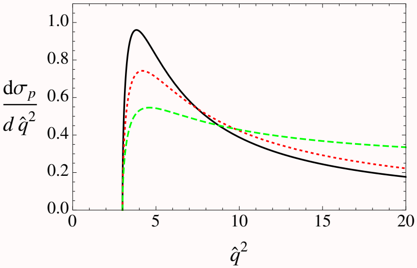
Example 1. $h \to V\bar{f}f \;/\; \bar{f}f \to Vh$ Isidori,(Manohar),Trott 1305.0663,1307.4051

$$\mathcal{A} \sim \mathbf{c_1}\left(\eta^{\mu\nu} - \frac{q^\mu q^\nu}{m_V^2}\right) + \mathbf{c_2}\left[\left(1+\frac{q^2}{m_V^2}\right)\eta^{\mu\nu} - \frac{2q^\mu q^\nu}{m_V^2}\right] + \dots$$

SMEFT: $c_2 = 0$
HEFT: $c_2 \neq 0$
(+ others)





SMEFT $\mathscr{L}_6$ vs. HEFT $\mathscr{L}_1$

two main classes of differences:

- interactions that are **correlated in SMEFT** and **decorrelated in HEFT**
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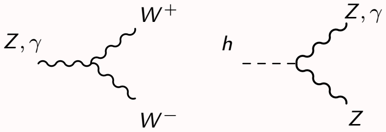
Example 2. VVV vs VVh interactions

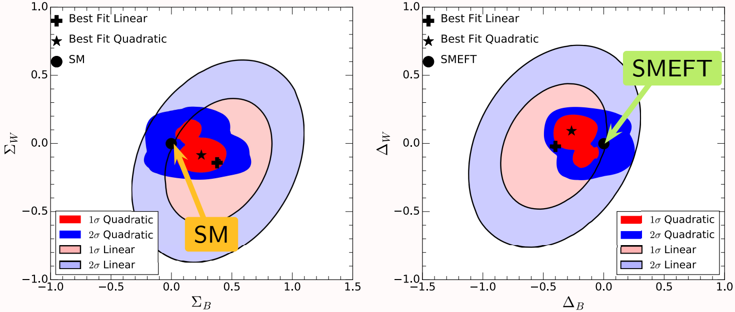
Éboli,Gonzalez-Garcia,Martines 2112.11468. also: IB et al 1311.1823,1604.06801



4 HEFT parameters:

$\Sigma_{W,B}$: SMEFT-like combinations

$\Delta_{W,B}$: orthogonal combinations



SMEFT $\mathscr{L}_6$ vs. HEFT $\mathscr{L}_1$

two main classes of differences:

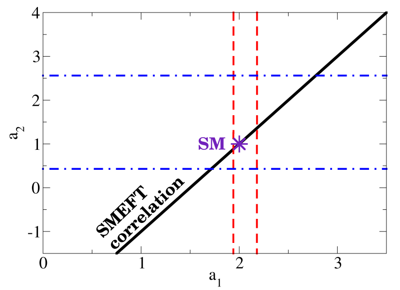
- interactions that are **correlated in SMEFT** and **decorrelated in HEFT**
- interactions that appear at **a lower order in HEFT** compared to SMEFT

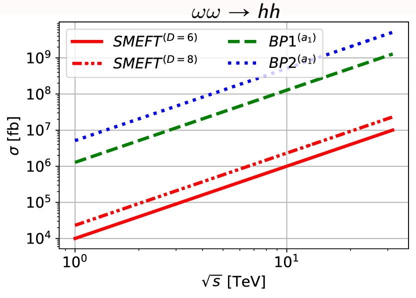
Example 3. $V_L V_L \to h^n$ at large s — Gomez-Ambrosio et al 2204.01763, Delgado et al 2311.04280

$$1 + a_1 \frac{h}{v} + a_2 \frac{h^2}{v^2} + \ldots$$

vs.

$$1 + c_1 \frac{(H^\dagger H)}{\Lambda^2} + c_2 \frac{(H^\dagger H)^2}{\Lambda^4} + \ldots$$





Are order-by-order considerations enough?

- if SMEFT is valid, the replacement $H \to h, \mathbf{U}$ must be an **unphysical field redefinition**
- if HEFT is more general, what UV scenarios does it capture that SMEFT doesn't?

phenomenologically:

- lately, a lot of interest in **dimension 8 SMEFT**

  Hays et al 2808.00442, Boughezal et al 2108.05337
  Degrande,Li 2303.10493, Ellis et al 2304.06663,
  Dawson et al 2110.06929,2205.01561,2212.03258, 23058,2305.07689
  Corbett et al 2102.02819,2107.07470,2110.03694,2304.03305 ...

  👉 relevant for poorly convergent SMEFT. HEFT known to work well in many of these cases
  eg. low mass 2HDM, composite Higgs, singlet extensions...

  👉 potentially relevant in fits: expands catalogue of BSM signals

  👎 hard to manage in full, too many parameters

- could HEFT represents **amore practical alternative** to dim 8 for phenomenology?

  👉 seems more efficient in resumming $(H^\dagger H)$ powers

  also geoSMEFT: Helset,Martin),Trott 2001.01453

- does HEFT point to phenomenological features that we would miss in a SMEFT analysis?
  how can we make sure not to leave any stone unturned?

all-orders comparison

SMEFT/HEFT geometrical interpretation

let us consider only the 4 scalar fields : they can be seen as coordinates on 4D manifold

Alonso, Jenkins, Manohar 1511.00724, 1605.03602

SMEFT $\sim$ **cartesian** coord. HEFT $\sim$ **polar** coord.

$$(\mathbb{R}^4) \qquad \vec{\phi} = \begin{pmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \\ \phi_4 \end{pmatrix} \qquad\qquad \vec{\phi} = (v+h)\exp\left[\frac{2\pi^i t_i}{v}\right]\begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

$$(SU(2)) \quad H = \frac{1}{\sqrt{2}}\begin{pmatrix} \phi_2 + i\phi_1 \\ \phi_4 - i\phi_3 \end{pmatrix} \qquad \mathbf{U} = \exp\left[\frac{\pi^i \sigma_i}{v}\right]$$

- accidental $SU(2)_L \times SU(2)_R \sim O(4)$ symmetry: $H^\dagger H = \dfrac{|\vec{\phi}|^2}{2}$
- field redefinition $\leftrightarrow$ change of coordinates
- physics can be associated to geometry of the field space, independent of coordinates

Physics – Geometry connection

The kinetic term corresponds to a metric in field space

$$\mathscr{L} = \frac{1}{2}\partial_\mu\phi^i\partial^\mu\phi^j g_{ij}(\phi) + \dots$$

it captures **all operators with 2 derivatives**, up to arbitrary dimensions. e.g.

$$\begin{aligned}
\partial_\mu H^\dagger\partial^\mu H\,(H^\dagger H)^n &= \frac{1}{2}\partial_\mu\vec{\phi}\cdot\partial^\mu\vec{\phi}\left(\frac{\vec{\phi}\cdot\vec{\phi}}{2}\right)^n &&\to\quad g_{ij} = \delta_{ij}\left(\frac{\vec{\phi}\cdot\vec{\phi}}{2}\right)^n\\
H^\dagger H\,\Box\,(H^\dagger H) &= -(\vec{\phi}\cdot\partial_\mu\vec{\phi})^2 &&\to\quad g_{ij} = -2\phi_i\phi_j\\
(iH^\dagger\partial_\mu H - i\partial_\mu H^\dagger H)^2 &= 4(\partial_\mu\vec{\phi}\; t_{3R}\;\vec{\phi})^2 &&\to\quad g_{ij} = 8(t_{3R}\phi)_i(t_{3R}\phi)_j
\end{aligned}$$

scattering amplitudes are proportional to the Riemann curvature invariants at the vacuum

$$\mathcal{A}(\phi_i\phi_j\to\phi_k\phi_l) = R_{ijkl}s_{ik} + R_{ikjl}s_{ij}$$

gauge sector and fermions can also be included in the formalism

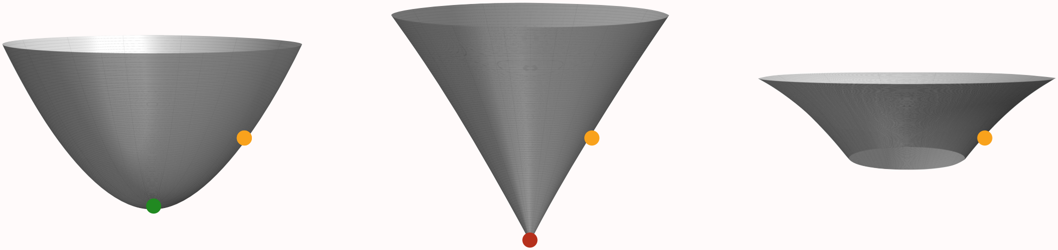
Cheung, Helset, Parra-Martinez 2111.03045, 2202.06972
Helset, Jenkins, Manohar 2210.08000
Assi, Helset, Manohar, Pagès, Shen 2307.03187
Cohen, Lu, Sutherland 2312.06748

Scenarios requiring HEFT

Cohen et al 2008.0597, 2108.03240, Banta et al 2110.02967. figs by D. Sutherland

SMEFT expands around the **$O(4)$ symmetric point**. HEFT expands around the **vacuum**.

there are cases where the SMEFT expansion **cannot be constructed**, or is not convergent at v



✔ SMEFT

✖ HEFT only

"loryons"

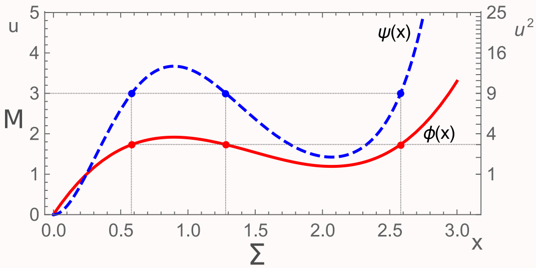
✖ HEFT only

BSM EWSB

what about operators with **more** than 2 derivatives?

Fibre bundle picture

Alminawi,IB,Davighi 2308.00017



fibre bundle (E, Σ, π)

E = total space

Σ = base space = spacetime with coord x^μ

$\pi : E \to \Sigma$ projection map

locally: $E = \Sigma \times M$

M = fibre = field space with coord u^i

$\phi(x) : \Sigma \to E$ is a **(local) section** of the bundle

- section $\neq$ coordinates on M: $\phi \neq u$
- field redefinition = change of section. if non derivative: $\sim$ diffeomorphism $f : E \to E$

1. we define a **metric g** on E
2. we are more careful in the **mapping** from geometry $\to$ Lagrangians (function on $E \to$ function on Σ)

Scalar Lagrangian from Fibre bundle geometry

E metric: bundle has coordinates $y^I = (x^\mu, u^i)$. Poincaré invariance $\to g^{IJ}$ independent of x^μ

$$g = g_{IJ} dy^I \otimes dy^J = \begin{pmatrix} dx^\mu & du^i \end{pmatrix} \begin{pmatrix} g_{\mu\nu}(u) & g_{\mu j}(u) \\ g_{\nu i}(u) & g_{ij}(u) \end{pmatrix} \begin{pmatrix} dx^\nu \\ du^j \end{pmatrix} = g_{\mu\nu} dx^\mu dx^\nu + 2 g_{\mu i} dx^\mu du^i + g_{ij} du^i du^j$$

pulling back to spacetime along the section ϕ $\to$ **Lagrangian**

$$u^i \to \phi^i(x) = (u^i \circ \phi)(x)\,, \qquad du^i \to \partial_\rho \phi^i(x)$$

$$g \to \mathscr{L} = \frac{1}{2}\eta^{\rho\sigma}\langle \partial_\rho \otimes \partial_\sigma, \phi^*(g)\rangle = \eta^{\rho\sigma}\left[\frac{1}{2} g_{\rho\sigma}(\phi) + g_{\rho i}(\phi)\partial_\sigma \phi^i + \frac{1}{2} g_{ij}(\phi)\partial_\rho\phi^i\partial_\sigma\phi^j\right]$$

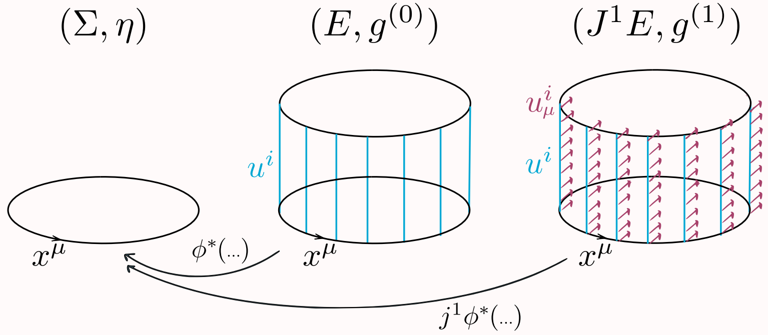
g_{ij} has the same interpretation as before. physics also requires

$$g_{\rho i}(\phi) \equiv 0 \qquad \eta^{\rho\sigma} g_{\rho\sigma}(\phi) = -2V(\phi)$$

$\to$ geometric description of the scalar potential!

Jet bundles

Saunders 1989. see also Craig,Lee 2307.15742



$j_x^i\phi$ = r-jet of ϕ at x = equivalence class containing sections identical up to r-th derivative

$J^r E$ = r-jet bundle = $\{j_x^r\phi | x \in \Sigma, \phi \in \Gamma_x(\pi)\}$ is a differentiable manifold.

we use only $J^1 E$

Scalar Lagrangian from 1-jet bundle geometry

J^1E metric: 1-jet bundle has coordinates $y^I = (x^\mu, u^i, u^i_\mu)$

$$g^{(1)} = g_{IJ} dy^I \otimes dy^J = \begin{pmatrix} dx^\mu & du^i & u^i_\mu \end{pmatrix} \begin{pmatrix} g_{\mu\nu} & g_{\mu j} & g^{\nu}_{\mu j} \\ g_{\nu i} & g_{ij} & g^{\nu}_{ij} \\ g^{\mu}_{\nu i} & g^{\mu}_{ij} & g^{\mu\nu}_{ij} \end{pmatrix} \begin{pmatrix} dx^\nu \\ du^j \\ du^i_\nu \end{pmatrix}$$

$$= g_{\mu\nu} dx^\mu dx^\nu + 2 g_{\mu i} dx^\mu du^i + 2 g^{\nu}_{\mu j} dx^\mu du^j_\nu + g_{ij} du^i du^j + 2 g^{\nu}_{ij} du^i du^j_\nu + g^{\mu\nu}_{ij} du^i_\mu du^j_\nu$$

pulling back to spacetime along the "prolongation" of the section $j^1\phi \to$ **Lagrangian**

$$u^i \to \phi^i(x)\,, \qquad u^i_\mu \to \partial_\mu \phi^i(x)\,, \qquad du^i \to \partial_\rho \phi^i(x)\,, \qquad du^i_\mu \to \partial_\rho \partial_\mu \phi^i(x)$$

$$g^{(1)} \to \mathscr{L} = \frac{1}{2}\eta^{\mu\nu} g_{\mu\nu} + g_{\mu i}\partial^\mu \phi^i + g^{\nu}_{\mu j}\partial^\mu \partial^\nu \phi^j + \frac{1}{2} g_{ij} \partial_\mu \phi^i \partial^\mu \phi^j + g^{\nu}_{ij} \partial_\rho \phi^i \partial^\rho \partial_\nu \phi^j + \frac{1}{2} g^{\mu\nu}_{ij} \partial_\rho \partial_\mu \phi^i \partial^\rho \partial_\nu \phi^j$$

- now all the metric entries are functions of $u_\mu, u^i_\mu \to \phi^i, \partial_\mu \phi^i$
- a 1-jet bundle metric maps to **a redundant basis of operators with up to 4 derivatives**

Scalar Lagrangian from 1-jet bundle metric: 1 scalar case

coordinates: (x^μ, u, u_μ).

→ we **expand** metric dependence on u_μ and leave dependence on u in analytic functions $A, B \ldots$

→ retain only terms leading to operators with **up to 4 derivatives**

$$\frac{g_{\mu\nu}}{\Lambda^4} = -\frac{\eta_{\mu\nu}}{2}V(u) + \left[\frac{u_\mu u_\nu}{\Lambda^4} + \frac{\eta_{\mu\nu}}{4}\frac{u_\rho u^\rho}{\Lambda^4}\right]\frac{J(u)}{2} + \left[\frac{u_\mu u_\nu}{\Lambda^4} + \frac{\eta_{\mu\nu}}{4}\frac{u_\rho u^\rho}{\Lambda^4}\right]\frac{u_\sigma u^\sigma}{\Lambda^4}\frac{K(u)}{2}$$

$$\frac{g_{\mu u}}{\Lambda^2} = \frac{u_\mu}{\Lambda^2}G(u) + \frac{u_\mu u_\rho u^\rho}{\Lambda^6}H(u)$$

$$g_{\mu u}^{\nu} = \delta_\mu^\nu E(u) + \frac{u^\nu u_\mu}{\Lambda^4}F_1(u) + \delta_\mu^\nu \frac{u_\rho u^\rho}{\Lambda^4}F_2(u)$$

$$g_{uu} = C(u) + \frac{u_\rho u^\rho}{\Lambda^4}D(u) \qquad \Lambda g_{uu}^{\mu} = \frac{u^\mu}{\Lambda}B(u) \qquad \Lambda^2 g_{uu}^{\mu\nu} = \eta^{\mu\nu}A(u)$$

pulls back to

$$\mathscr{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi\,(C + 2G + J) - \Lambda(\Box\phi)E - \Lambda^4 V$$
$$+ \frac{\partial_\mu\partial_\nu\phi\partial^\mu\partial^\nu\phi}{\Lambda^2}\frac{A}{2} + \frac{\partial_\mu\partial_\nu\phi\partial^\mu\phi\partial^\nu\phi}{\Lambda^3}(B + F_1) + \frac{(\Box\phi)(\partial_\mu\phi\partial^\mu\phi)}{\Lambda^3}F_2 + \frac{(\partial_\mu\phi\partial^\mu\phi)^2}{\Lambda^4}\frac{D + 2H + K}{2}$$

Scalar Lagrangian from 1-jet bundle metric: 1 scalar case

coordinates: (x^μ, u, u_μ).

→ we **expand** metric dependence on u_μ and leave dependence on u in analytic functions $A, B \ldots$

→ retain only terms leading to operators with **up to 4 derivatives**

$$\frac{g_{\mu\nu}}{\Lambda^4} = -\frac{\eta_{\mu\nu}}{2} V(u) + \left[\frac{u_\mu u_\nu}{\Lambda^4} + \frac{\eta_{\mu\nu}}{4}\frac{u_\rho u^\rho}{\Lambda^4}\right]\frac{J(u)}{2} + \left[\frac{u_\mu u_\nu}{\Lambda^4} + \frac{\eta_{\mu\nu}}{4}\frac{u_\rho u^\rho}{\Lambda^4}\right]\frac{u_\sigma u^\sigma}{\Lambda^4}\frac{K(u)}{2}$$

$$\frac{g_{\mu u}}{\Lambda^2} = \frac{u_\mu}{\Lambda^2} G(u) + \frac{u_\mu u_\rho u^\rho}{\Lambda^6} H(u)$$

$$g_{\mu u}^{\nu} = \delta_\mu^\nu E(u) + \frac{u^\nu u_\mu}{\Lambda^4} F_1(u) + \delta_\mu^\nu \frac{u_\rho u^\rho}{\Lambda^4} F_2(u)$$

$$g_{uu} = C(u) + \frac{u_\rho u^\rho}{\Lambda^4} D(u) \qquad \Lambda g_{uu}^{\mu} = \frac{u^\mu}{\Lambda} B(u) \qquad \Lambda^2 g_{uu}^{\mu\nu} = \eta^{\mu\nu} A(u)$$

pulls back to

$$\mathscr{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi\left(C + 2G + J - 2E'\right) - \Lambda^4 V$$

blue = can be removed via EOM

$$+\frac{\partial_\mu\partial_\nu\phi\partial^\mu\partial^\nu\phi}{\Lambda^2}\frac{A}{2} + \frac{\partial_\mu\partial_\nu\phi\partial^\mu\phi\partial^\nu\phi}{\Lambda^3}(B + F_1 - 2F_2) + \frac{(\partial_\mu\phi\partial^\mu\phi)^2}{\Lambda^4}\frac{D + 2H + K - 2F_2'}{2}$$

Extension to higher derivatives

metric $g^{(r)}$ of a r-jet bundle $\longrightarrow$ **redundant** basis of operators with up to $2(r+1)$ deriv.

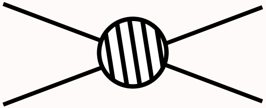
r-jet bundle has coordinates $y^I = (x^\mu, u^i, u^i_{\mu_1}, u^i_{\mu_1\mu_2}, \ldots, u^i_{\mu_1\ldots\mu_r})$

$$g^{(r)} = \begin{pmatrix} dx^\mu & du^i & du^i_{\mu_1} & \cdots & du^i_{\mu_1\ldots\mu_r} \end{pmatrix} \begin{pmatrix} g_{\mu\nu} & g_{\mu j} & g^{\nu_1}_{\mu j} & \cdots & g^{\nu_1\ldots\nu_r}_{\mu j} \\ g_{\nu i} & g_{ij} & g^{\nu_1}_{ij} & \cdots & g^{\nu_1\ldots\nu_r}_{ij} \\ g^{\mu_1}_{\nu i} & g^{\mu_1}_{ij} & g^{\mu_1\nu_1}_{ij} & \cdots & g^{\mu_1\nu_1\ldots\nu_r}_{ij} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ g^{\mu_1\ldots\mu_r}_{\nu i} & g^{\mu_1\ldots\mu_r}_{ij} & g^{\mu_1\ldots\mu_r\nu_1}_{ij} & \cdots & g^{\mu_1\ldots\mu_r\nu_1\ldots\nu_r}_{ij} \end{pmatrix} \begin{pmatrix} dx^\nu \\ du^j \\ du^j_{\nu_1} \\ \cdots \\ du^j_{\nu_1\ldots\nu_r} \end{pmatrix}$$

- arbitrary internal symmetries (or absence thereof) can always be implemented
- many redundancies! different metric entries mapping to same operators, IBP, EOM, diffeos...

Alternative approaches

classification of independent on-shell amplitude structures, rather than EFT interactions



$\times \quad F(s,t)$

a **finite** set of structures compatible with Lorentz + QED + QCD (“primaries”)

$\times$

infinite series in kinematic invariants (“descendants”, “stripped contact terms”)

pseudo-observables: Gonzalez-Alonso,Greljo,Isidori,Marzocca 1412.6038,1504.04018,1507.02555
BSM primaries: Chang,Chen,Liu,Luty 2212.06215,2304.06063,2312.03821
on-shell amplitudes: Shadmi et al 1909.10551,2008.09652,2112.09688,2301.11349

- 👍 **maximally general** parameterization of BSM effects. EW gauge-invariance relations fully broken.
- 👎 interpretation still requires matching to an EFT or model
- **?** which UV scenarios require this approach? attainable experimentally?

Alminawi,IB,Cohen pheno exploration, in progress

Wrapping up

- SMEFT is a very popular theory for indirect new physics searches.
  an ambitious program underway for **LHC**, interest in combining with **other experiments**
- HEFT is an alternative to SMEFT, that adopts a different description of the scalar sector
- order-by-order phenomenological comparisons highlight phenomenological differences.
  differential geometry proved successful to address a deeper, all-orders comparison,
- HEFT could have phenomenological relevance for not-very-decoupled theories
- ongoing work on geometrical description using field space bundles and their higher **jet bundles**
  - gives a geometric interpretation to **scalar potential and higher-∂ terms**
  - significant degeneracy. relation to amplitudes less clear than in field space picture
  - gauge and fermion fields not incorporated yet
- alternative approaches are based on scattering amplitudes rather than Lagrangian formulations
  - implications for phenomenology and interpretation still under development

Backup slides

SMEFT/HEFT in the Fibre bundle picture

SMEFT/HEFT = a theory of 4 scalar fields, with a $O(4)$ symmetry: $u^i, i = 1,2,3,4$.

bundle metric entries

$$g_{\mu\nu}(u) = -\frac{\eta_{\mu\nu}\Lambda^4}{2} V\left[\frac{u\cdot u}{\Lambda^2}\right] \qquad\qquad g_{\mu i}(u) = 0$$

$$g_{ij}(u) = \delta_{ij} A\left[\frac{u\cdot u}{\Lambda^2}\right] + \delta_{ik}\delta_{jl}\frac{u^k u^l}{\Lambda^2} B\left[\frac{u\cdot u}{\Lambda^2}\right]$$

gives

$$\mathscr{L} = \frac{1}{2}\partial_\mu\vec{\phi}\cdot\partial^\mu\vec{\phi}\, A\left[\frac{\vec{\phi}\cdot\vec{\phi}}{\Lambda^2}\right] + \frac{1}{2\Lambda^2}(\vec{\phi}\cdot\partial_\mu\vec{\phi})(\vec{\phi}\cdot\partial^\mu\vec{\phi})\, B\left[\frac{\vec{\phi}\cdot\vec{\phi}}{\Lambda^2}\right] - \Lambda^4 V\left[\frac{\vec{\phi}\cdot\vec{\phi}}{\Lambda^2}\right]$$

$\rightarrow$ most general effective Lagrangian with **up to 2** derivatives!

Scalar Lagrangian from 1-jet bundle metric: SMEFT/HEFT case

similar procedure as above, requiring also appropriate $O(4)$ transformations $\rightarrow$ more structures!

now $A, B, C\dots$ are analytic functions of $(u\cdot u/\Lambda^2)$

$$
\begin{aligned}
\frac{g_{\mu\nu}}{\Lambda^4} &= -\frac{\eta_{\mu\nu}}{2}V + \left[\frac{u_\mu\cdot u_\nu}{\Lambda^4} + \frac{\eta_{\mu\nu}}{4}\frac{u_\rho\cdot u^\rho}{\Lambda^4}\right]\frac{J_0}{2} + \left[\frac{u\cdot u_\mu\, u\cdot u_\nu}{\Lambda^6} + \frac{\eta_{\mu\nu}}{4}\frac{(u\cdot u_\rho)^2}{\Lambda^4}\right]\frac{J_1}{2}\\
&+ \left[\frac{u_\mu\cdot u_\nu}{\Lambda^4} + \frac{\eta_{\mu\nu}}{4}\frac{u_\rho\cdot u^\rho}{\Lambda^2}\right]\frac{u_\rho\cdot u^\rho}{\Lambda^4}\frac{K_0}{2} + \left[\frac{u_\rho\cdot u_\mu\, u^\rho\cdot u_\nu}{\Lambda^6} + \frac{\eta_{\mu\nu}}{4}\frac{(u_\rho\cdot u_\sigma)^2}{\Lambda^4}\right]\frac{K_1}{2}\\
\frac{g_{\mu j}}{\Lambda^2} &= \frac{u_{j\mu}}{\Lambda^2}G_0 + \frac{u_j\, u\cdot u_\mu}{\Lambda^4}G_1 + \frac{u_{j\mu}\, u_\rho\cdot u^\rho}{\Lambda^6}H_0 + \frac{u_{j\rho}\, u_\mu\cdot u^\rho}{\Lambda^6}H_1 + \left[\frac{u_j\, u\cdot u_\mu\, u_\rho\cdot u^\rho}{\Lambda^8} + \frac{u_{j\mu}(u\cdot u_\rho)^2}{\Lambda^8}\right]\frac{H_2}{2}\\
&+ \left[\frac{u_j\, u_\mu\cdot u_\rho\, u\cdot u^\rho}{\Lambda^8} + \frac{u_{j\rho}\, u\cdot u_\mu\, u\cdot u^\rho}{\Lambda^8}\right]\frac{H_3}{2} + \frac{u_j\, u\cdot u_\mu(u\cdot u_\rho)^2}{\Lambda^{10}}H_4\\
g^\nu_{\mu j} &= \delta^\nu_\mu\frac{u_j}{\Lambda}E + \frac{u_j\, u^\nu\cdot u_\mu}{\Lambda^5}F_{10} + \frac{u^\nu_j\, u\cdot u_\mu + u\cdot u^\nu\, u_{j\mu}}{2\Lambda^5}F_{11} + \frac{u_j\, u\cdot u^\nu\, u\cdot u_\mu}{\Lambda^7}F_{12} + \delta^\nu_\mu\frac{u_j\, u_\rho\cdot u^\rho}{\Lambda^5}F_{20} + \delta^\nu_\mu\frac{u_{j\rho}\, u\cdot u^\rho}{\Lambda^5}F_{21} + \delta^\nu_\mu\frac{u_j(u\cdot u^\rho)^2}{\Lambda^7}F_{22}\\
g_{ij} &= \delta_{ij}C_0 + \frac{u_iu_j}{\Lambda^2}C_1 + \delta_{ij}\frac{u_\rho\cdot u^\rho}{\Lambda^4}D_0 + \frac{u_{i\rho}u^\rho_j}{\Lambda^4}D_1 + \left[\delta_{ij}\frac{(u\cdot u_\rho)^2}{\Lambda^6} + \frac{u_iu_j\, u_\rho\cdot u^\rho}{\Lambda^6}\right]\frac{D_2}{2} + \frac{(u_iu_{j\rho} + u_ju_{i\rho})\, u\cdot u^\rho}{\Lambda^6}\frac{D_3}{2} + \frac{u_iu_j(u\cdot u_\rho)^2}{\Lambda^8}D_4\\
\Lambda g^\mu_{ij} &= \frac{u^\mu_i u_j}{\Lambda^3}B_0 + \frac{u_iu^\mu_j}{\Lambda^3}B_1 + \delta_{ij}\frac{u\cdot u^\mu}{\Lambda^3}B_2 + \frac{u_iu_j\, u\cdot u^\mu}{\Lambda^5}B_3\\
\Lambda^2 g^{\mu\nu}_{ij} &= \eta^{\mu\nu}\delta_{ij}A_0 + \eta^{\mu\nu}\frac{u_iu_j}{\Lambda^2}A_1
\end{aligned}
$$

Scalar Lagrangian from 1-jet bundle metric: SMEFT/HEFT case

similar procedure as above, requiring also appropriate $O(4)$ transformations → more structures!

leading to

$$
\begin{aligned}
\mathscr{L} = &\frac{1}{2}(\partial_\mu\phi\cdot\partial^\mu\phi)\,(C_0+2G_0+J_0) + \frac{(\partial_\mu\phi\cdot\phi)^2}{\Lambda^2}\frac{C_1+2G_1+J_1}{2} + (\Box\phi\cdot\phi)E - \Lambda^4 V\\
&+ \frac{(\partial_\mu\partial_\nu\phi\cdot\partial^\mu\partial^\nu\phi)}{\Lambda^2}\frac{A_0}{2} + \frac{(\partial_\mu\partial_\nu\phi\cdot\phi)(\partial^\mu\partial^\nu\phi\cdot\phi)}{\Lambda^4}\frac{A_1}{2}\\
&+ \frac{(\partial_\mu\partial_\nu\phi\cdot\partial^\mu\phi)(\partial^\nu\phi\cdot\phi)}{\Lambda^4}\frac{B_0+B_1+2B_2+2F_{11}}{2} + \frac{(\partial_\mu\partial_\nu\phi\cdot\phi)(\partial^\mu\phi\cdot\partial^\nu\phi)}{\Lambda^4}\frac{B_0+B_1+2F_{10}}{2}\\
&+ \frac{(\Box\phi\cdot\phi)(\partial_\mu\phi\cdot\partial^\mu\phi)}{\Lambda^4}F_{20} + \frac{(\Box\phi\cdot\partial_\mu\phi)(\partial^\mu\phi\cdot\phi)}{\Lambda^4}F_{21} + \frac{(\partial_\mu\phi\cdot\partial^\mu\phi)^2}{\Lambda^4}\frac{D_0+2H_0+K_0}{2} + \frac{(\partial_\mu\phi\cdot\partial_\nu\phi)^2}{\Lambda^4}\frac{D_1+2H_1+K_1}{2}\\
&+ \frac{(\partial_\mu\partial_\nu\phi\cdot\phi)(\partial^\mu\phi\cdot\phi)(\partial^\nu\phi\cdot\phi)}{\Lambda^6}(B_3+F_{12}) + \frac{(\Box\phi\cdot\phi)(\partial_\mu\phi\cdot\phi)^2}{\Lambda^6}F_{22}\\
&+ \frac{(\partial_\mu\phi\cdot\partial^\mu\phi)(\partial_\nu\phi\cdot\phi)^2}{\Lambda^6}\frac{D_2+2H_2+K_2}{2} + \frac{(\partial_\mu\phi\cdot\partial_\nu\phi)(\partial^\mu\phi\cdot\phi)(\partial^\nu\phi\cdot\phi)}{\Lambda^6}\frac{D_3+2H_3+K_3}{2}\\
&+ \frac{(\partial_\mu\phi\cdot\phi)^4}{\Lambda^8}\frac{D_4+2H_4+K_4}{2}
\end{aligned}
$$

Scalar Lagrangian from 1-jet bundle metric: SMEFT/HEFT case

similar procedure as above, requiring also appropriate $O(4)$ transformations $\rightarrow$ more structures!

leading to blue = can be removed via EOM

$$
\begin{aligned}
\mathscr{L} = \; & \frac{1}{2}(\partial_\mu\phi\cdot\partial^\mu\phi)(C_0+2G_0+J_0-2E) + \frac{(\partial_\mu\phi\cdot\phi)^2}{\Lambda^2}\frac{C_1+2G_1+J_1-4E'}{2} - \Lambda^4 V \\
& + \frac{(\partial_\mu\partial_\nu\phi\cdot\partial^\mu\partial^\nu\phi)}{\Lambda^2}\frac{A_0}{2} + \frac{(\partial_\mu\partial_\nu\phi\cdot\phi)(\partial^\mu\partial^\nu\phi\cdot\phi)}{\Lambda^4}\frac{A_1}{2} \\
& + \frac{(\partial_\mu\partial_\nu\phi\cdot\partial^\mu\phi)(\partial^\nu\phi\cdot\phi)}{\Lambda^4}\frac{B_0+B_1+2B_2+2F_{11}-4F_{20}-2F_{21}}{2} \\
& + \frac{(\partial_\mu\partial_\nu\phi\cdot\phi)(\partial^\mu\phi\cdot\partial^\nu\phi)}{\Lambda^4}\frac{B_0+B_1+2F_{10}-2F_{21}}{2} + \frac{(\partial_\mu\phi\cdot\partial^\mu\phi)^2}{\Lambda^4}\frac{D_0+2H_0+K_{10}-2F_{20}}{2} \\
& + \frac{(\partial_\mu\phi\cdot\partial_\nu\phi)^2}{\Lambda^4}\frac{D_1+2H_1+K_1-2F_{21}}{2} + \frac{(\partial_\mu\partial_\nu\phi\cdot\phi)(\partial^\mu\phi\cdot\phi)(\partial^\nu\phi\cdot\phi)}{\Lambda^6}(B_3+F_{12}-2F_{22}) \\
& + \frac{(\partial_\mu\phi\cdot\partial^\mu\phi)(\partial_\nu\phi\cdot\phi)^2}{\Lambda^6}\frac{D_2+2H_2+K_2-4F'_{20}-2F_{22}}{2} \\
& + \frac{(\partial_\mu\phi\cdot\partial_\nu\phi)(\partial^\mu\phi\cdot\phi)(\partial^\nu\phi\cdot\phi)}{\Lambda^6}\frac{D_3+2H_3+K_3-4F'_{21}-4F_{22}}{2} + \frac{(\partial_\mu\phi\cdot\phi)^4}{\Lambda^8}\frac{D_4+2H_4+K_4-4F'_{22}}{2},
\end{aligned}
$$

geoSMEFT operators

Helset,Martin,Trott 2001.08001

	Mass Dimension				
Field space connection	6	8	10	12	14
$h_{IJ}(\phi)(D_\mu\phi)^I(D^\mu\phi)^J$	2	2	2	2	2
$g_{AB}(\phi)\mathcal{W}^A_{\mu\nu}\mathcal{W}^{B,\mu\nu}$	3	4	4	4	4
$k_{IJA}(\phi)(D^\mu\phi)^I(D^\nu\phi)^J\mathcal{W}^A_{\mu\nu}$	0	3	4	4	4
$f_{ABC}(\phi)\mathcal{W}^A_{\mu\nu}\mathcal{W}^{B,\nu\rho}\mathcal{W}^{C,\mu}_\rho$	1	2	2	2	2
$Y^u_{pr}(\phi)\bar{Q}u+$ h.c.	$2\,N_f^2$	$2\,N_f^2$	$2\,N_f^2$	$2\,N_f^2$	$2\,N_f^2$
$Y^d_{pr}(\phi)\bar{Q}d+$ h.c.	$2\,N_f^2$	$2\,N_f^2$	$2\,N_f^2$	$2\,N_f^2$	$2\,N_f^2$
$Y^e_{pr}(\phi)\bar{L}e+$ h.c.	$2\,N_f^2$	$2\,N_f^2$	$2\,N_f^2$	$2\,N_f^2$	$2\,N_f^2$
$d^{e,pr}_A(\phi)\bar{L}\sigma_{\mu\nu}e\mathcal{W}^{\mu\nu}_A+$ h.c.	$4\,N_f^2$	$6\,N_f^2$	$6\,N_f^2$	$6\,N_f^2$	$6\,N_f^2$
$d^{u,pr}_A(\phi)\bar{Q}\sigma_{\mu\nu}u\mathcal{W}^{\mu\nu}_A+$ h.c.	$4\,N_f^2$	$6\,N_f^2$	$6\,N_f^2$	$6\,N_f^2$	$6\,N_f^2$
$d^{d,pr}_A(\phi)\bar{Q}\sigma_{\mu\nu}d\mathcal{W}^{\mu\nu}_A+$ h.c.	$4\,N_f^2$	$6\,N_f^2$	$6\,N_f^2$	$6\,N_f^2$	$6\,N_f^2$
$L^{\psi_R}_{pr,A}(\phi)(D^\mu\phi)^J(\bar{\psi}_{p,R}\gamma_\mu\sigma_A\psi_{r,R})$	N_f^2	N_f^2	N_f^2	N_f^2	N_f^2
$L^{\psi_L}_{pr,A}(\phi)(D^\mu\phi)^J(\bar{\psi}_{p,L}\gamma_\mu\sigma_A\psi_{r,L})$	$2\,N_f^2$	$4\,N_f^2$	$4\,N_f^2$	$4\,N_f^2$	$4\,N_f^2$

$$(D_\mu H^\dagger D^\mu H)(H^\dagger H)^n$$
$$(D_\mu H^\dagger \sigma^i D^\mu H)(H^\dagger \sigma^i H)(H^\dagger H)^n$$

$$(B_{\mu\nu}B^{\mu\nu})(H^\dagger H)^n$$
$$(W^i_{\mu\nu}W^{i\mu\nu})(H^\dagger H)^n$$
$$(B_{\mu\nu}W^{i\mu\nu})(H^\dagger \sigma^i H)(H^\dagger H)^n$$
$$(W^i_{\mu\nu}W^{j\mu\nu})(H^\dagger \sigma^i H)(H^\dagger \sigma^j H)(H^\dagger H)^n$$