SMEFT vs HEFT
for new physics searches at LHC

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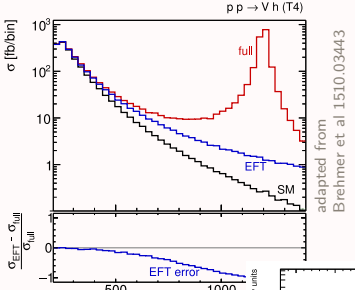
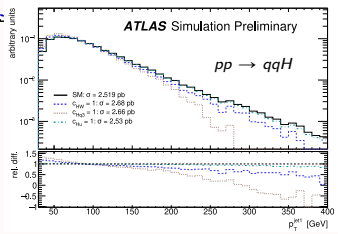
Effective Field Theories for BSM physics

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

→ "indirect searches" of New Physics at LHC and precision experiments





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**

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**

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

$C_i =$ 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 ∼ 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	$f^{ABC} G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK} W^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu \varphi\right)^\star \left(\varphi^\dagger D_\mu \varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK} \widetilde{W}^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\, \widetilde{G}^A_{\mu\nu} G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i \overleftrightarrow{D}^I_\mu \varphi)(\bar{l}_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\widetilde{\varphi}\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{e}_p \gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\, \widetilde{W}^I_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \widetilde{\varphi}\, W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{q}_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{\varphi}\, B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^\dagger i \overleftrightarrow{D}^I_\mu \varphi)(\bar{q}_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{u}_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{d}_p \gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$

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

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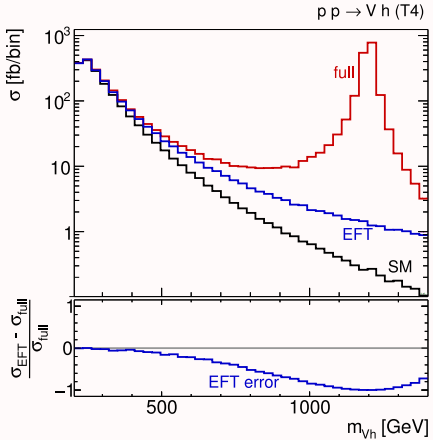
SMEFT for new physics searches at LHC

Top-Down

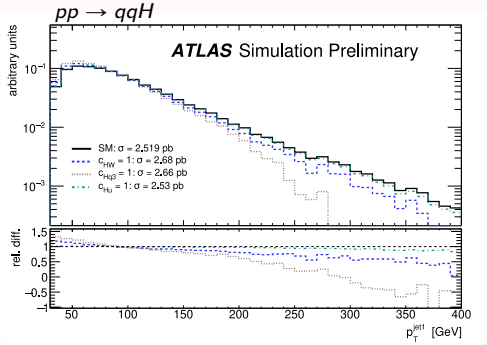
heavy BSM leaves residual footprints at visible energies



adapted from Brehmer,Freitas,López-Val,Plehn 1510.03443

Bottom-Up

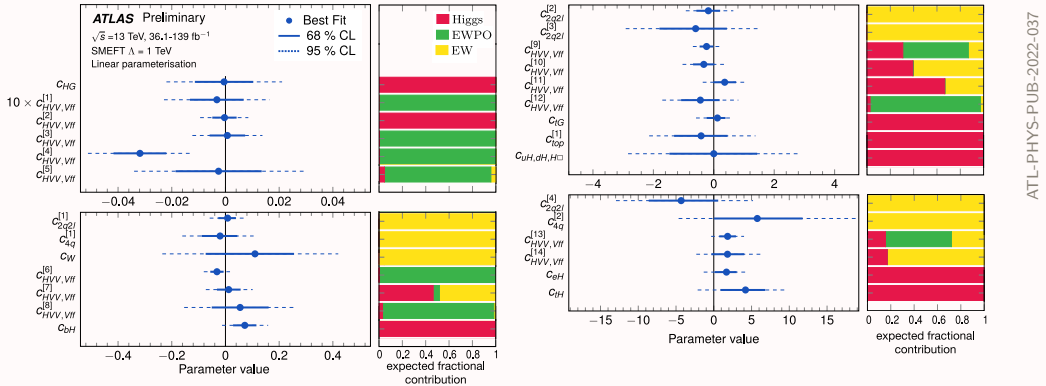
SMEFT operators cause deviations from SM predictions



ATLAS ATL-PHYS-PUB-2019-042

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



A legitimate concern: EFT validity

- Λ is **unknown**
- LHC measurements often reach into **high energies** $(m, p_T, m_T \dots)$
- often **measurement** precision is not sufficient to guarantee that deviations from SM are small

A legitimate concern: EFT validity

- Λ is **unknown**
- LHC measurements often reach into **high energies** $(m, p_T, m_T \dots)$
- often **measurement** precision is not sufficient to guarantee that deviations from SM are small

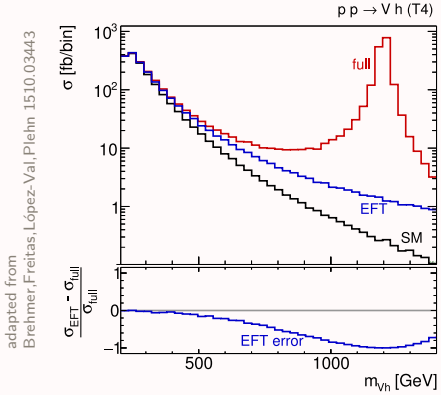
is $(E, v) \ll \Lambda$ a valid assumption?

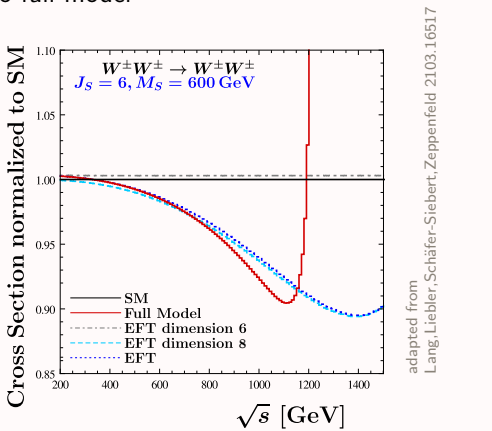
are $d \geqslant 8$ terms always negligible?

can there be UV scenarios for which SMEFT does not describe the low-E limit?

Possible issues with $d = 6$ SMEFT: poor convergence

EFT obtained from matching to full model

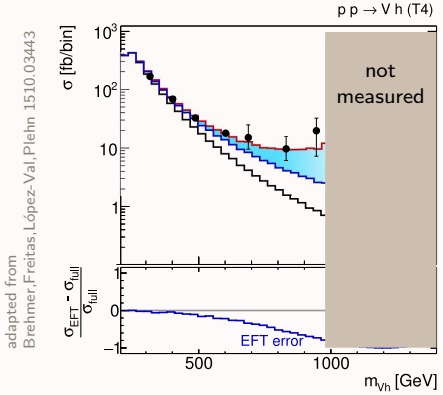




$d = 6$ contribution dominant at low m_{VH}

$d = 6$ contribution negligible

Possible issues with $d = 6$ SMEFT: poor convergence



adapted from Brehmer,Freitas,López-Val,Plehn 1510.03443

👎 **top-down**: truncated EFT does not reproduce full model at high-E

👎 **bottom-up**: fit to data finds wrong values of C_i

→ several recent works on $d = 8$ impact

Hays,Martin,Sanz,Setford 1808.00442
Boughezal,Mereghetti,Petriello 2106.05337
Dawson et al 2110.06929, 2205.01561, 2212.03258, 2305.07689
Degrande, Li 2303.10493, Ellis,Mimasu,Zampedri 2304.06663
Corbett et al 2102.02819, 2107.07470, 2110.03694,2304.03305

op. bases: Murphy 2005.00059, Li,Ren,Shu,Xiao,Yu 2005.00008
RGE: Chala,Guedes et al 2106.05291, 2205.03301
matching: Chakrabortty et al 2306.09103, 2308.03849

SMEFT at $d = 8$: Murphy basis

$1 : X^4,\ X^3X',\ X^2X'^2$

$Q^{(1)}_{G^4}$	$(G^A_{\mu\nu}G^{A\mu\nu})(G^B_{\rho\sigma}G^{B\rho\sigma})$	$Q^{(1)}_{G^2W^2}$	$(W^I_{\mu\nu}W^{I\mu\nu})(G^A_{\rho\sigma}G^{A\rho\sigma})$
$Q^{(2)}_{G^4}$	$(G^A_{\mu\nu}\widetilde{G}^{A\mu\nu})(G^B_{\rho\sigma}\widetilde{G}^{B\rho\sigma})$	$Q^{(2)}_{G^2W^2}$	$(W^I_{\mu\nu}\widetilde{W}^{I\mu\nu})(G^A_{\rho\sigma}G^{A\rho\sigma})$
$Q^{(3)}_{G^4}$	$(G^A_{\mu\nu}G^{B\mu\nu})(G^A_{\rho\sigma}G^{B\rho\sigma})$	$Q^{(3)}_{G^2W^2}$	$(W^I_{\mu\nu}G^{A\mu\nu})(W^I_{\rho\sigma}G^{A\rho\sigma})$
$Q^{(4)}_{G^4}$	$(G^A_{\mu\nu}\widetilde{G}^{B\mu\nu})(G^A_{\rho\sigma}\widetilde{G}^{B\rho\sigma})$	$Q^{(4)}_{G^2W^2}$	$(W^I_{\mu\nu}\widetilde{G}^{A\mu\nu})(W^I_{\rho\sigma}\widetilde{G}^{A\rho\sigma})$
$Q^{(5)}_{G^4}$	$(G^A_{\mu\nu}G^{A\mu\nu})(G^B_{\rho\sigma}\widetilde{G}^{B\rho\sigma})$	$Q^{(5)}_{G^2W^2}$	$(W^I_{\mu\nu}\widetilde{W}^{I\mu\nu})(G^A_{\rho\sigma}G^{A\rho\sigma})$
$Q^{(6)}_{G^4}$	$(G^A_{\mu\nu}G^{B\mu\nu})(G^A_{\rho\sigma}\widetilde{G}^{B\rho\sigma})$	$Q^{(6)}_{G^2W^2}$	$(W^I_{\mu\nu}W^{I\mu\nu})(G^A_{\rho\sigma}\widetilde{G}^{A\rho\sigma})$
$Q^{(7)}_{G^4}$	$d^{ABE}d^{CDE}(G^A_{\mu\nu}G^{B\mu\nu})(G^C_{\rho\sigma}G^{D\rho\sigma})$	$Q^{(7)}_{G^2W^2}$	$(W^I_{\mu\nu}G^{A\mu\nu})(W^I_{\rho\sigma}\widetilde{G}^{A\rho\sigma})$
$Q^{(8)}_{G^4}$	$d^{ABE}d^{CDE}(G^A_{\mu\nu}\widetilde{G}^{B\mu\nu})(G^C_{\rho\sigma}\widetilde{G}^{D\rho\sigma})$	$Q^{(1)}_{G^2B^2}$	$(B_{\mu\nu}B^{\mu\nu})(G^A_{\rho\sigma}G^{A\rho\sigma})$
$Q^{(9)}_{G^4}$	$d^{ABE}d^{CDE}(G^A_{\mu\nu}G^{B\mu\nu})(G^C_{\rho\sigma}\widetilde{G}^{D\rho\sigma})$	$Q^{(2)}_{G^2B^2}$	$(B_{\mu\nu}\widetilde{B}^{\mu\nu})(G^A_{\rho\sigma}\widetilde{G}^{A\rho\sigma})$
$Q^{(1)}_{W^4}$	$(W^I_{\mu\nu}W^{I\mu\nu})(W^J_{\rho\sigma}W^{J\rho\sigma})$	$Q^{(3)}_{G^2B^2}$	$(B_{\mu\nu}G^{A\mu\nu})(B_{\rho\sigma}G^{A\rho\sigma})$
$Q^{(2)}_{W^4}$	$(W^I_{\mu\nu}\widetilde{W}^{I\mu\nu})(W^J_{\rho\sigma}\widetilde{W}^{J\rho\sigma})$	$Q^{(4)}_{G^2B^2}$	$(B_{\mu\nu}\widetilde{G}^{A\mu\nu})(B_{\rho\sigma}\widetilde{G}^{A\rho\sigma})$
$Q^{(3)}_{W^4}$	$(W^I_{\mu\nu}W^{J\mu\nu})(W^I_{\rho\sigma}W^{J\rho\sigma})$	$Q^{(5)}_{G^2B^2}$	$(B_{\mu\nu}\widetilde{B}^{\mu\nu})(G^A_{\rho\sigma}G^{A\rho\sigma})$
$Q^{(4)}_{W^4}$	$(W^I_{\mu\nu}\widetilde{W}^{J\mu\nu})(W^I_{\rho\sigma}\widetilde{W}^{J\rho\sigma})$	$Q^{(6)}_{G^2B^2}$	$(B_{\mu\nu}B^{\mu\nu})(G^A_{\rho\sigma}\widetilde{G}^{A\rho\sigma})$
$Q^{(5)}_{W^4}$	$(W^I_{\mu\nu}W^{I\mu\nu})(W^J_{\rho\sigma}\widetilde{W}^{J\rho\sigma})$	$Q^{(7)}_{G^2B^2}$	$(B_{\mu\nu}G^{A\mu\nu})(B_{\rho\sigma}\widetilde{G}^{A\rho\sigma})$
$Q^{(6)}_{W^4}$	$(W^I_{\mu\nu}W^{J\mu\nu})(W^I_{\rho\sigma}\widetilde{W}^{J\rho\sigma})$	$Q^{(1)}_{W^2B^2}$	$(B_{\mu\nu}B^{\mu\nu})(W^I_{\rho\sigma}W^{I\rho\sigma})$
$Q^{(1)}_{B^4}$	$(B_{\mu\nu}B^{\mu\nu})(B_{\rho\sigma}B^{\rho\sigma})$	$Q^{(2)}_{W^2B^2}$	$(B_{\mu\nu}\widetilde{B}^{\mu\nu})(W^I_{\rho\sigma}\widetilde{W}^{I\rho\sigma})$
$Q^{(2)}_{B^4}$	$(B_{\mu\nu}\widetilde{B}^{\mu\nu})(B_{\rho\sigma}\widetilde{B}^{\rho\sigma})$	$Q^{(3)}_{W^2B^2}$	$(B_{\mu\nu}W^{I\mu\nu})(B_{\rho\sigma}W^{I\rho\sigma})$
$Q^{(3)}_{B^4}$	$(B_{\mu\nu}B^{\mu\nu})(B_{\rho\sigma}\widetilde{B}^{\rho\sigma})$	$Q^{(4)}_{W^2B^2}$	$(B_{\mu\nu}\widetilde{W}^{I\mu\nu})(B_{\rho\sigma}\widetilde{W}^{I\rho\sigma})$
$Q^{(1)}_{G^3B}$	$d^{ABC}(B_{\mu\nu}G^{A\mu\nu})(G^B_{\rho\sigma}G^{C\rho\sigma})$	$Q^{(5)}_{W^2B^2}$	$(B_{\mu\nu}\widetilde{B}^{\mu\nu})(W^I_{\rho\sigma}W^{I\rho\sigma})$
$Q^{(2)}_{G^3B}$	$d^{ABC}(B_{\mu\nu}\widetilde{G}^{A\mu\nu})(G^B_{\rho\sigma}\widetilde{G}^{C\rho\sigma})$	$Q^{(6)}_{W^2B^2}$	$(B_{\mu\nu}B^{\mu\nu})(W^I_{\rho\sigma}\widetilde{W}^{I\rho\sigma})$
$Q^{(3)}_{G^3B}$	$d^{ABC}(B_{\mu\nu}\widetilde{G}^{A\mu\nu})(G^B_{\rho\sigma}G^{C\rho\sigma})$	$Q^{(7)}_{W^2B^2}$	$(B_{\mu\nu}W^{I\mu\nu})(B_{\rho\sigma}\widetilde{W}^{I\rho\sigma})$
$Q^{(4)}_{G^3B}$	$d^{ABC}(B_{\mu\nu}G^{A\mu\nu})(G^B_{\rho\sigma}\widetilde{G}^{C\rho\sigma})$		

$2 : H^8$

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

$3 : H^6D^2$

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

$4 : H^4D^4$

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

$5 : X^3H^2$

$Q^{(1)}_{G^3H^2}$	$f^{ABC}(H^\dagger H)G^{A\mu}_\nu G^{B\rho}_\mu G^{C\nu}_\rho$	$Q^{(1)}_{G^2H^4}$	$(H^\dagger H)^2G^A_{\mu\nu}G^{A\mu\nu}$
$Q^{(2)}_{G^3H^2}$	$f^{ABC}(H^\dagger H)G^{A\mu}_\nu G^{B\rho}_\mu\widetilde{G}^{C\nu}_\rho$	$Q^{(2)}_{G^2H^4}$	$(H^\dagger H)^2\widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$
$Q^{(1)}_{W^3H^2}$	$\epsilon^{IJK}(H^\dagger H)W^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$	$Q^{(1)}_{W^2H^4}$	$(H^\dagger H)^2W^I_{\mu\nu}W^{I\mu\nu}$
$Q^{(2)}_{W^3H^2}$	$\epsilon^{IJK}(H^\dagger H)W^{I\nu}_\mu W^{J\rho}_\nu\widetilde{W}^{K\mu}_\rho$	$Q^{(2)}_{W^2H^4}$	$(H^\dagger H)^2\widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$
$Q^{(1)}_{W^2BH^2}$	$\epsilon^{IJK}(H^\dagger\tau^I H)B^\nu_\mu W^{J\rho}_\nu W^{K\mu}_\rho$	$Q^{(3)}_{W^2H^4}$	$(H^\dagger\tau^I H)(H^\dagger\tau^J H)W^I_{\mu\nu}W^{J\mu\nu}$
$Q^{(2)}_{W^2BH^2}$	$\epsilon^{IJK}(H^\dagger\tau^I H)(\widetilde{B}^{\mu\nu}W^J_{\nu\rho}W^K_\mu{}^\rho + B^{\mu\nu}W^J_{\nu\rho}\widetilde{W}^{K\rho}_\mu)$	$Q^{(4)}_{W^2H^4}$	$(H^\dagger\tau^I H)(H^\dagger\tau^J H)\widetilde{W}^I_{\mu\nu}W^{J\mu\nu}$
		$Q^{(1)}_{WBH^4}$	$(H^\dagger H)(H^\dagger\tau^I H)W^I_{\mu\nu}B^{\mu\nu}$
		$Q^{(2)}_{WBH^4}$	$(H^\dagger H)(H^\dagger\tau^I H)\widetilde{W}^I_{\mu\nu}B^{\mu\nu}$
		$Q^{(1)}_{B^2H^4}$	$(H^\dagger H)^2B_{\mu\nu}B^{\mu\nu}$
		$Q^{(2)}_{B^2H^4}$	$(H^\dagger H)^2\widetilde{B}_{\mu\nu}B^{\mu\nu}$

$6 : X^2H^4$

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

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

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

$8 : XH^4D^2$

$Q^{(1)}_{W^2H^4D^2}$	$(H^\dagger H)(D^\mu H^\dagger\tau^I D^\nu H)W^I_{\mu\nu}$
$Q^{(2)}_{W^2H^4D^2}$	$(H^\dagger H)(D^\mu H^\dagger\tau^I D^\nu H)\widetilde{W}^I_{\mu\nu}$
$Q^{(3)}_{W^2H^4D^2}$	$\epsilon^{IJK}(H^\dagger\tau^I H)(D^\mu H^\dagger\tau^J D^\nu H)W^K_{\mu\nu}$
$Q^{(4)}_{W^2H^4D^2}$	$\epsilon^{IJK}(H^\dagger\tau^I H)(D^\mu H^\dagger\tau^J D^\nu H)\widetilde{W}^K_{\mu\nu}$
$Q^{(1)}_{BH^4D^2}$	$(H^\dagger H)(D^\mu H^\dagger D^\nu H)B_{\mu\nu}$
$Q^{(2)}_{BH^4D^2}$	$(H^\dagger H)(D^\mu H^\dagger D^\nu H)\widetilde{B}_{\mu\nu}$

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

SMEFT at $d = 8$: Murphy basis

$\mathbf{9 : \psi^2 X^2 H + h.c.}$		$\mathbf{9 : \psi^2 X^2 H + h.c.}$	
$Q^{(1)}_{leG^2H}$	$(\bar{l}_p e_r) H G^A_{\mu\nu} G^{A\mu\nu}$	$Q^{(1)}_{leWBH}$	$(\bar{l}_p e_r) \tau^I H W^I_{\mu\nu} B^{\mu\nu}$
$Q^{(2)}_{leG^2H}$	$(\bar{l}_p e_r) H \widetilde{G}^A_{\mu\nu} G^{A\mu\nu}$	$Q^{(2)}_{leWBH}$	$(\bar{l}_p e_r) \tau^I H \widetilde{W}^I_{\mu\nu} B^{\mu\nu}$
$Q^{(1)}_{leW^2H}$	$(\bar{l}_p e_r) H W^I_{\mu\nu} W^{I\mu\nu}$	$Q^{(3)}_{leWBH}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I H W^I_{\mu\nu} B_\nu{}^\rho$
$Q^{(2)}_{leW^2H}$	$(\bar{l}_p e_r) H \widetilde{W}^I_{\mu\nu} W^{I\mu\nu}$	$Q^{(1)}_{leB^2H}$	$(\bar{l}_p e_r) H B_{\mu\nu} B^{\mu\nu}$
$Q^{(3)}_{leW^2H}$	$\epsilon^{IJK} (\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I H W^J_{\rho\nu} W^{K\rho}_\mu$	$Q^{(2)}_{leB^2H}$	$(\bar{l}_p e_r) H \widetilde{B}_{\mu\nu} B^{\mu\nu}$
$Q^{(1)}_{quG^2H}$	$(\bar{q}_p u_r) \widetilde{H} G^A_{\mu\nu} G^{A\mu\nu}$	$Q^{(1)}_{qdG^2H}$	$(\bar{q}_p d_r) H G^A_{\mu\nu} G^{A\mu\nu}$
$Q^{(2)}_{quG^2H}$	$(\bar{q}_p u_r) \widetilde{H} \widetilde{G}^A_{\mu\nu} G^{A\mu\nu}$	$Q^{(2)}_{qdG^2H}$	$(\bar{q}_p d_r) H \widetilde{G}^A_{\mu\nu} G^{A\mu\nu}$
$Q^{(3)}_{quG^2H}$	$d^{ABC} (\bar{q}_p T^A u_r) \widetilde{H} G^B_{\mu\nu} G^{C\mu\nu}$	$Q^{(3)}_{qdG^2H}$	$d^{ABC} (\bar{q}_p T^A d_r) H G^B_{\mu\nu} G^{C\mu\nu}$
$Q^{(4)}_{quG^2H}$	$d^{ABC} (\bar{q}_p T^A u_r) \widetilde{H} \widetilde{G}^B_{\mu\nu} G^{C\mu\nu}$	$Q^{(4)}_{qdG^2H}$	$d^{ABC} (\bar{q}_p T^A d_r) H \widetilde{G}^B_{\mu\nu} G^{C\mu\nu}$
$Q^{(5)}_{quG^2H}$	$f^{ABC} (\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{H} G^B_{\mu\rho} G^C_{\nu}{}^\rho$	$Q^{(5)}_{qdG^2H}$	$f^{ABC} (\bar{q}_p \sigma^{\mu\nu} T^A d_r) H G^B_{\mu\rho} G^C_{\nu}{}^\rho$
$Q^{(1)}_{quGWH}$	$(\bar{q}_p T^A u_r) \tau^I \widetilde{H} G^A_{\mu\nu} W^{I\mu\nu}$	$Q^{(1)}_{qdGWH}$	$(\bar{q}_p T^A d_r) \tau^I H G^A_{\mu\nu} W^{I\mu\nu}$
$Q^{(2)}_{quGWH}$	$(\bar{q}_p T^A u_r) \tau^I \widetilde{H} \widetilde{G}^A_{\mu\nu} W^{I\mu\nu}$	$Q^{(2)}_{qdGWH}$	$(\bar{q}_p T^A d_r) \tau^I H \widetilde{G}^A_{\mu\nu} W^{I\mu\nu}$
$Q^{(3)}_{quGWH}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tau^I \widetilde{H} G^A_{\mu\rho} W^{I\rho}_\nu$	$Q^{(3)}_{qdGWH}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \tau^I H G^A_{\mu\rho} W^{I\rho}_\nu$
$Q^{(1)}_{quGBH}$	$(\bar{q}_p T^A u_r) \widetilde{H} G^A_{\mu\nu} B^{\mu\nu}$	$Q^{(1)}_{qdGBH}$	$(\bar{q}_p T^A d_r) H G^A_{\mu\nu} B^{\mu\nu}$
$Q^{(2)}_{quGBH}$	$(\bar{q}_p T^A u_r) \widetilde{H} \widetilde{G}^A_{\mu\nu} B^{\mu\nu}$	$Q^{(2)}_{qdGBH}$	$(\bar{q}_p T^A d_r) H \widetilde{G}^A_{\mu\nu} B^{\mu\nu}$
$Q^{(3)}_{quGBH}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{H} G^A_{\mu\rho} B_\nu{}^\rho$	$Q^{(3)}_{qdGBH}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) H G^A_{\mu\rho} B_\nu{}^\rho$
$Q^{(1)}_{quW^2H}$	$(\bar{q}_p u_r) \widetilde{H} W^I_{\mu\nu} W^{I\mu\nu}$	$Q^{(1)}_{qdW^2H}$	$(\bar{q}_p d_r) H W^I_{\mu\nu} W^{I\mu\nu}$
$Q^{(2)}_{quW^2H}$	$(\bar{q}_p u_r) \widetilde{H} \widetilde{W}^I_{\mu\nu} W^{I\mu\nu}$	$Q^{(2)}_{qdW^2H}$	$(\bar{q}_p d_r) H \widetilde{W}^I_{\mu\nu} W^{I\mu\nu}$
$Q^{(3)}_{quW^2H}$	$\epsilon^{IJK} (\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{H} W^J_{\mu\rho} W^{K\rho}_\nu$	$Q^{(3)}_{qdW^2H}$	$\epsilon^{IJK} (\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I H W^J_{\mu\rho} W^{K\rho}_\nu$
$Q^{(1)}_{quWBH}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{H} W^I_{\mu\nu} B_\nu{}^\rho$	$Q^{(1)}_{qdWBH}$	$(\bar{q}_p d_r) \tau^I H W^I_{\mu\nu} B^{\mu\nu}$
$Q^{(1)}_{quWBH}$	$(\bar{q}_p u_r) \tau^I \widetilde{H} W^I_{\mu\nu} B^{\mu\nu}$	$Q^{(2)}_{qdWBH}$	$(\bar{q}_p d_r) \tau^I H \widetilde{W}^I_{\mu\nu} B^{\mu\nu}$
$Q^{(2)}_{quWBH}$	$(\bar{q}_p u_r) \tau^I \widetilde{H} \widetilde{W}^I_{\mu\nu} B^{\mu\nu}$	$Q^{(3)}_{qdWBH}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I H W^I_{\mu\rho} B_\nu{}^\rho$
$Q^{(1)}_{quB^2H}$	$(\bar{q}_p u_r) \widetilde{H} B_{\mu\nu} B^{\mu\nu}$	$Q^{(1)}_{qdB^2H}$	$(\bar{q}_p d_r) H B_{\mu\nu} B^{\mu\nu}$
$Q^{(2)}_{quB^2H}$	$(\bar{q}_p u_r) \widetilde{H} \widetilde{B}_{\mu\nu} B^{\mu\nu}$	$Q^{(2)}_{qdB^2H}$	$(\bar{q}_p d_r) H \widetilde{B}_{\mu\nu} B^{\mu\nu}$

$\mathbf{10 : \psi^2 X H^3 + h.c.}$	
$Q^{(1)}_{leWH^3}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I H (H^\dagger H) W^I_{\mu\nu}$
$Q^{(2)}_{leWH^3}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) H (H^\dagger \tau^I H) W^I_{\mu\nu}$
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}	$(\bar{q}_p \sigma^{\mu\nu} d_r) H (H^\dagger H) B_{\mu\nu}$

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

$\mathbf{12 : \psi^2 H^5 + h.c.}$	
$Q_{le^2H^5}$	$(H^\dagger H)^2 (\bar{l}_p e_r H)$
$Q_{qu^2H^5}$	$(H^\dagger H)^2 (\bar{q}_p u_r \widetilde{H})$
$Q_{qd^2H^5}$	$(H^\dagger H)^2 (\bar{q}_p d_r H)$

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

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

SMEFT at $d = 8$: Murphy basis

$\psi^2 X^2 D$

$Q^{(1)}_{uG^2D}$	$i(\bar{q}_r\gamma^\mu\overleftrightarrow{D}^\nu q_r)G^A_{\mu\rho}G^{A\rho}_\nu$
$Q^{(2)}_{uG^2D}$	$f^{ABC}(\bar{q}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)G^B_{\mu\rho}G^{C\rho}_\nu$
$Q^{(3)}_{uG^2D}$	$id^{ABC}(\bar{q}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)G^B_{\mu\rho}G^{C\rho}_\nu$
$Q^{(1)}_{uW^2D}$	$i(\bar{q}_r\gamma^\mu\overleftrightarrow{D}^\nu q_r)W^I_{\mu\rho}W^{I\rho}_\nu$
$Q^{(2)}_{uW^2D}$	$\epsilon^{IJK}(\bar{q}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu q_r)W^J_{\mu\rho}W^{K\rho}_\nu$
Q_{eB^2D}	$i(\bar{q}_r\gamma^\mu\overleftrightarrow{D}^\nu q_r)B_{\mu\rho}B_\nu{}^\rho$
$Q^{(1)}_{uG^2D}$	$i(\bar{u}_r\gamma^\mu\overleftrightarrow{D}^\nu u_r)G^A_{\mu\rho}G^{A\rho}_\nu$
$Q^{(2)}_{uG^2D}$	$f^{ABC}(\bar{u}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu u_r)G^B_{\mu\rho}G^{C\rho}_\nu$
$Q^{(3)}_{uG^2D}$	$id^{ABC}(\bar{u}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu u_r)G^B_{\mu\rho}G^{C\rho}_\nu$
Q_{uW^2D}	$i(\bar{u}_r\gamma^\mu\overleftrightarrow{D}^\nu u_r)W^I_{\mu\rho}W^{I\rho}_\nu$
Q_{uB^2D}	$i(\bar{u}_r\gamma^\mu\overleftrightarrow{D}^\nu u_r)B_{\mu\rho}B_\nu{}^\rho$
$Q^{(1)}_{dG^2D}$	$i(\bar{d}_r\gamma^\mu\overleftrightarrow{D}^\nu d_r)G^A_{\mu\rho}G^{A\rho}_\nu$
$Q^{(2)}_{dG^2D}$	$f^{ABC}(\bar{d}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu d_r)G^B_{\mu\rho}G^{C\rho}_\nu$
$Q^{(3)}_{dG^2D}$	$id^{ABC}(\bar{d}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu d_r)G^B_{\mu\rho}G^{C\rho}_\nu$
Q_{dW^2D}	$i(\bar{d}_r\gamma^\mu\overleftrightarrow{D}^\nu d_r)W^I_{\mu\rho}W^{I\rho}_\nu$
Q_{dB^2D}	$i(\bar{d}_r\gamma^\mu\overleftrightarrow{D}^\nu d_r)B_{\mu\rho}B_\nu{}^\rho$

$\psi^2 X^2 D$

$Q^{(4)}_{uG^2D}$	$if^{ABC}(\bar{q}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)(G^B_{\mu\rho}\widetilde{G}^{C\rho}_\nu - \widetilde{G}^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(5)}_{uG^2D}$	$f^{ABC}(\bar{q}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)(G^B_{\mu\rho}\widetilde{G}^{C\rho}_\nu + \widetilde{G}^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(1)}_{uGW D}$	$(\bar{q}_r\gamma^\mu T^A\tau^I\overleftrightarrow{D}^\nu q_r)(G^A_{\mu\rho}W^I_{\nu\rho} - G_{\nu\rho}W^I_{\mu\rho})$
$Q^{(2)}_{uGW D}$	$i(\bar{q}_r\gamma^\mu T^A\tau^I\overleftrightarrow{D}^\nu q_r)(G^A_{\mu\rho}W^I_{\nu\rho} + G^A_{\nu\rho}W^I_{\mu\rho})$
$Q^{(3)}_{uGW D}$	$(\bar{q}_r\gamma^\mu T^A\tau^I\overleftrightarrow{D}^\nu q_r)(G^A_{\mu\rho}\widetilde{W}^I_{\nu\rho} - G^A_{\nu\rho}\widetilde{W}^I_{\mu\rho})$
$Q^{(4)}_{uGW D}$	$i(\bar{q}_r\gamma^\mu T^A\tau^I\overleftrightarrow{D}^\nu q_r)(G^A_{\mu\rho}\widetilde{W}^I_{\nu\rho} + G^A_{\nu\rho}\widetilde{W}^I_{\mu\rho})$
$Q^{(1)}_{qGBD}$	$(\bar{q}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}G^{A\rho}_\nu - B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(2)}_{qGBD}$	$i(\bar{q}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}G^{A\rho}_\nu + B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(3)}_{qGBD}$	$(\bar{q}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}\widetilde{G}^{A\rho}_\nu - B_{\nu\rho}\widetilde{G}^{A\rho}_\mu)$
$Q^{(4)}_{qGBD}$	$i(\bar{q}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}\widetilde{G}^{A\rho}_\nu + B_{\nu\rho}\widetilde{G}^{A\rho}_\mu)$
$Q^{(3)}_{qWW D}$	$i\epsilon^{IJK}(\bar{q}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu q_r)(W^J_{\mu\rho}\widetilde{W}^{K\rho}_\nu - \widetilde{W}^J_{\mu\rho}W^{K\rho}_\nu)$
$Q^{(4)}_{qW^2D}$	$\epsilon^{IJK}(\bar{q}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu q_r)(W^J_{\mu\rho}\widetilde{W}^{K\rho}_\nu + \widetilde{W}^J_{\mu\rho}W^{K\rho}_\nu)$
$Q^{(1)}_{qWBD}$	$(\bar{q}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}W^{I\rho}_\nu - B_{\nu\rho}W^{I\rho}_\mu)$
$Q^{(2)}_{qWBD}$	$i(\bar{q}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}W^{I\rho}_\nu + B_{\nu\rho}W^{I\rho}_\mu)$
$Q^{(3)}_{qWBD}$	$(\bar{q}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}\widetilde{W}^{I\rho}_\nu - B_{\nu\rho}\widetilde{W}^{I\rho}_\mu)$
$Q^{(4)}_{qWBD}$	$i(\bar{q}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu q_r)(B_{\mu\rho}\widetilde{W}^{I\rho}_\nu + B_{\nu\rho}\widetilde{W}^{I\rho}_\mu)$
$Q^{(1)}_{uGBD}$	$if^{ABC}(\bar{q}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu u_r)(G^B_{\mu\rho}\widetilde{G}^{C\rho}_\nu - \widetilde{G}^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(2)}_{uGBD}$	$f^{ABC}(\bar{q}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu u_r)(G^B_{\mu\rho}\widetilde{G}^{C\rho}_\nu + \widetilde{G}^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(3)}_{uGBD}$	$(\bar{u}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu u_r)(B_{\mu\rho}G^{A\rho}_\nu - B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(4)}_{uGBD}$	$i(\bar{u}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu u_r)(B_{\mu\rho}G^{A\rho}_\nu + B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(5)}_{uGBD}$	$(\bar{u}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu u_r)(B_{\mu\rho}\widetilde{G}^{A\rho}_\nu - B_{\nu\rho}\widetilde{G}^{A\rho}_\mu)$
$Q^{(6)}_{uGBD}$	$i(\bar{u}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu u_r)(B_{\mu\rho}\widetilde{G}^{A\rho}_\nu + B_{\nu\rho}\widetilde{G}^{A\rho}_\mu)$
$Q^{(1)}_{dGBD}$	$if^{ABC}(\bar{d}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu d_r)(G^B_{\mu\rho}\widetilde{G}^{C\rho}_\nu - \widetilde{G}^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(2)}_{dGBD}$	$f^{ABC}(\bar{d}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu d_r)(G^B_{\mu\rho}\widetilde{G}^{C\rho}_\nu + \widetilde{G}^B_{\mu\rho}G^{C\rho}_\nu)$
$Q^{(3)}_{dGBD}$	$(\bar{d}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu d_r)(B_{\mu\rho}G^{A\rho}_\nu - B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(4)}_{dGBD}$	$i(\bar{d}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu d_r)(B_{\mu\rho}G^{A\rho}_\nu + B_{\nu\rho}G^{A\rho}_\mu)$
$Q^{(5)}_{dGBD}$	$(\bar{d}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu d_r)(B_{\mu\rho}\widetilde{G}^{A\rho}_\nu - B_{\nu\rho}\widetilde{G}^{A\rho}_\mu)$
$Q^{(6)}_{dGBD}$	$i(\bar{d}_r\gamma^\mu T^A\overleftrightarrow{D}^\nu d_r)(B_{\mu\rho}\widetilde{G}^{A\rho}_\nu + B_{\nu\rho}\widetilde{G}^{A\rho}_\mu)$

$\psi^2 X^2 D$

Q_{eG^2D}	$i(\bar{l}_r\gamma^\mu\overleftrightarrow{D}^\nu l_r)G^A_{\mu\rho}G^{A\rho}_\nu$
$Q^{(1)}_{eW^2D}$	$i(\bar{l}_r\gamma^\mu\overleftrightarrow{D}^\nu l_r)W^I_{\mu\rho}W^{I\rho}_\nu$
$Q^{(2)}_{eW^2D}$	$\epsilon^{IJK}(\bar{l}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu l_r)W^J_{\mu\rho}W^{K\rho}_\nu$
Q_{eB^2D}	$i(\bar{l}_r\gamma^\mu\overleftrightarrow{D}^\nu l_r)B_{\mu\rho}B_\nu{}^\rho$
$Q_{e\tilde{G}^2D}$	$i(\bar{e}_r\gamma^\mu\overleftrightarrow{D}^\nu e_r)G^A_{\mu\rho}G^{A\rho}_\nu$
$Q_{e\tilde{W}^2D}$	$i(\bar{e}_r\gamma^\mu\overleftrightarrow{D}^\nu e_r)W^I_{\mu\rho}W^{I\rho}_\nu$
$Q_{e\tilde{B}^2D}$	$i(\bar{e}_r\gamma^\mu\overleftrightarrow{D}^\nu e_r)B_{\mu\rho}B_\nu{}^\rho$

$\psi^2 X^2 D$

$Q^{(3)}_{lW^2D}$	$i\epsilon^{IJK}(\bar{l}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu l_r)(W^J_{\mu\rho}\widetilde{W}^{K\rho}_\nu - \widetilde{W}^J_{\mu\rho}W^{K\rho}_\nu)$
$Q^{(4)}_{lW^2D}$	$\epsilon^{IJK}(\bar{l}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu l_r)(W^J_{\mu\rho}\widetilde{W}^{K\rho}_\nu + \widetilde{W}^J_{\mu\rho}W^{K\rho}_\nu)$
$Q^{(1)}_{lWBD}$	$(\bar{l}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu l_r)(B_{\mu\rho}W^{I\rho}_\nu - B_{\nu\rho}W^{I\rho}_\mu)$
$Q^{(2)}_{lWBD}$	$i(\bar{l}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu l_r)(B_{\mu\rho}W^{I\rho}_\nu + B_{\nu\rho}W^{I\rho}_\mu)$
$Q^{(3)}_{lWBD}$	$(\bar{l}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu l_r)(B_{\mu\rho}\widetilde{W}^{I\rho}_\nu - B_{\nu\rho}\widetilde{W}^{I\rho}_\mu)$
$Q^{(4)}_{lWBD}$	$i(\bar{l}_r\gamma^\mu\tau^I\overleftrightarrow{D}^\nu l_r)(B_{\mu\rho}\widetilde{W}^{I\rho}_\nu + B_{\nu\rho}\widetilde{W}^{I\rho}_\mu)$

$(\bar{R}R)XH^2D$

$Q^{(1)}_{eWH^2D}$	$(\bar{e}_r\gamma^\mu e_r)D^\mu(H^\dagger\tau^I H)W^I_{\mu\nu}$
$Q^{(2)}_{eWH^2D}$	$(\bar{e}_r\gamma^\mu e_r)D^\mu(H^\dagger\tau^I H)\widetilde{W}^I_{\mu\nu}$
$Q^{(3)}_{eWH^2D}$	$(\bar{e}_r\gamma^\mu e_r)(H^\dagger\overleftrightarrow{D}^I H)W^I_{\mu\nu}$
$Q^{(4)}_{eWH^2D}$	$(\bar{e}_r\gamma^\mu e_r)(H^\dagger\overleftrightarrow{D}^I H)\widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{eBH^2D}$	$(\bar{e}_r\gamma^\mu e_r)D^\mu(H^\dagger H)B_{\mu\nu}$
$Q^{(2)}_{eBH^2D}$	$(\bar{e}_r\gamma^\mu e_r)D^\mu(H^\dagger H)\widetilde{B}_{\mu\nu}$
$Q^{(3)}_{eBH^2D}$	$(\bar{e}_r\gamma^\mu e_r)(H^\dagger\overleftrightarrow{D}^\mu H)B_{\mu\nu}$
$Q^{(4)}_{eBH^2D}$	$(\bar{e}_r\gamma^\mu e_r)(H^\dagger\overleftrightarrow{D}^\mu H)\widetilde{B}_{\mu\nu}$
$Q^{(1)}_{uGH^2D}$	$(\bar{u}_r\gamma^\mu T^A u_r)D^\mu(H^\dagger H)G^A_{\mu\nu}$
$Q^{(2)}_{uGH^2D}$	$(\bar{u}_r\gamma^\mu T^A u_r)D^\mu(H^\dagger H)\widetilde{G}^A_{\mu\nu}$
$Q^{(3)}_{uGH^2D}$	$(\bar{u}_r\gamma^\mu T^A u_r)(H^\dagger\overleftrightarrow{D}^\mu H)G^A_{\mu\nu}$
$Q^{(4)}_{uGH^2D}$	$(\bar{u}_r\gamma^\mu T^A u_r)(H^\dagger\overleftrightarrow{D}^\mu H)\widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{uWH^2D}$	$(\bar{u}_r\gamma^\mu u_r)D^\mu(H^\dagger\tau^I H)W^I_{\mu\nu}$
$Q^{(2)}_{uWH^2D}$	$(\bar{u}_r\gamma^\mu u_r)D^\mu(H^\dagger\tau^I H)\widetilde{W}^I_{\mu\nu}$
$Q^{(3)}_{uWH^2D}$	$(\bar{u}_r\gamma^\mu u_r)(H^\dagger\overleftrightarrow{D}^I H)W^I_{\mu\nu}$
$Q^{(4)}_{uWH^2D}$	$(\bar{u}_r\gamma^\mu u_r)(H^\dagger\overleftrightarrow{D}^I H)\widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{uBH^2D}$	$(\bar{u}_r\gamma^\mu u_r)D^\mu(H^\dagger H)B_{\mu\nu}$
$Q^{(2)}_{uBH^2D}$	$(\bar{u}_r\gamma^\mu u_r)D^\mu(H^\dagger H)\widetilde{B}_{\mu\nu}$
$Q^{(3)}_{uBH^2D}$	$(\bar{u}_r\gamma^\mu u_r)(H^\dagger\overleftrightarrow{D}^\mu H)B_{\mu\nu}$
$Q^{(4)}_{uBH^2D}$	$(\bar{u}_r\gamma^\mu u_r)(H^\dagger\overleftrightarrow{D}^\mu H)\widetilde{B}_{\mu\nu}$

$(\bar{R}R)XH^2D$

$Q^{(1)}_{dGH^2D}$	$(\bar{d}_r\gamma^\mu T^A d_r)D^\mu(H^\dagger H)G^A_{\mu\nu}$
$Q^{(2)}_{dGH^2D}$	$(\bar{d}_r\gamma^\mu T^A d_r)D^\mu(H^\dagger H)\widetilde{G}^A_{\mu\nu}$
$Q^{(3)}_{dGH^2D}$	$(\bar{d}_r\gamma^\mu T^A d_r)(H^\dagger\overleftrightarrow{D}^\mu H)G^A_{\mu\nu}$
$Q^{(4)}_{dGH^2D}$	$(\bar{d}_r\gamma^\mu T^A d_r)(H^\dagger\overleftrightarrow{D}^\mu H)\widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{dWH^2D}$	$(\bar{d}_r\gamma^\mu\tau^I d_r)D^\mu(H^\dagger\tau^I H)W^I_{\mu\nu}$
$Q^{(2)}_{dWH^2D}$	$(\bar{d}_r\gamma^\mu\tau^I d_r)D^\mu(H^\dagger\tau^I H)\widetilde{W}^I_{\mu\nu}$
$Q^{(3)}_{dWH^2D}$	$(\bar{d}_r\gamma^\mu d_r)(H^\dagger\overleftrightarrow{D}^I H)W^I_{\mu\nu}$
$Q^{(4)}_{dWH^2D}$	$(\bar{d}_r\gamma^\mu d_r)(H^\dagger\overleftrightarrow{D}^I H)\widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{dBH^2D}$	$(\bar{d}_r\gamma^\mu d_r)D^\mu(H^\dagger H)B_{\mu\nu}$
$Q^{(2)}_{dBH^2D}$	$(\bar{d}_r\gamma^\mu d_r)D^\mu(H^\dagger H)\widetilde{B}_{\mu\nu}$
$Q^{(3)}_{dBH^2D}$	$(\bar{d}_r\gamma^\mu d_r)(H^\dagger\overleftrightarrow{D}^\mu H)B_{\mu\nu}$
$Q^{(4)}_{dBH^2D}$	$(\bar{d}_r\gamma^\mu d_r)(H^\dagger\overleftrightarrow{D}^\mu H)\widetilde{B}_{\mu\nu}$

$(\bar{R}R)\tau XH^2D$

$Q^{(1)}_{udGH^2}$ + h.c.	$(\bar{u}_r\gamma^\mu T^A d_r)(\widetilde{H}^\dagger D^\mu H)G^A_{\mu\nu}$
$Q^{(2)}_{udGH^2}$ + h.c.	$(\bar{u}_r\gamma^\mu T^A d_r)(\widetilde{H}^\dagger\overleftrightarrow{D}^\mu H)\widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{udWH^2}$ + h.c.	$(\bar{u}_r\gamma^\mu d_r)(\widetilde{H}^\dagger\overleftrightarrow{D}^I H)W^I_{\mu\nu}$
$Q^{(2)}_{udWH^2}$ + h.c.	$(\bar{u}_r\gamma^\mu d_r)(\widetilde{H}^\dagger\overleftrightarrow{D}^I H)\widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{udBH^2}$ + h.c.	$(\bar{u}_r\gamma^\mu d_r)(\widetilde{H}^\dagger D^\mu H)B_{\mu\nu}$
$Q^{(2)}_{udBH^2}$ + h.c.	$(\bar{u}_r\gamma^\mu d_r)(\widetilde{H}^\dagger\overleftrightarrow{D}^\mu H)\widetilde{B}_{\mu\nu}$

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

SMEFT at $d = 8$: Murphy basis

$15 : (\bar{L}L)XH^2D$

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

$15 : (\bar{L}L)XH^2D$

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

$16 : \psi^2XHD^2 + \text{h.c.}$

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

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

$Q^{(1)}_{leH^3D^2}$	$(D_\mu H^\dagger D^\mu H)(\bar{l}_pe_rH)$
$Q^{(2)}_{leH^3D^2}$	$(D_\mu H^\dagger\tau^I D^\mu H)(\bar{l}_pe_r\tau^I H)$
$Q^{(3)}_{leH^3D^2}$	$(D_\mu H^\dagger D_\nu H)(\bar{l}_p\sigma^{\mu\nu}e_rH)$
$Q^{(4)}_{leH^3D^2}$	$(D_\mu H^\dagger\tau^I D_\nu H)(\bar{l}_p\sigma^{\mu\nu}e_r\tau^I H)$
$Q^{(5)}_{leH^3D^2}$	$(H^\dagger D_\mu H)(\bar{l}_pe_rD^\mu H)$
$Q^{(6)}_{leH^3D^2}$	$(H^\dagger D_\mu H)(\bar{l}_p\sigma^{\mu\nu}e_rD_\nu H)$
$Q^{(1)}_{quH^3D^2}$	$(D_\mu H^\dagger D^\mu H)(\bar{q}_pu_r\tilde{H})$
$Q^{(2)}_{quH^3D^2}$	$(D_\mu H^\dagger\tau^I D^\mu H)(\bar{q}_pu_r\tau^I\tilde{H})$
$Q^{(3)}_{quH^3D^2}$	$(D_\mu H^\dagger D_\nu H)(\bar{q}_p\sigma^{\mu\nu}u_r\tilde{H})$
$Q^{(4)}_{quH^3D^2}$	$(D_\mu H^\dagger\tau^I D_\nu H)(\bar{q}_p\sigma^{\mu\nu}u_r\tau^I\tilde{H})$
$Q^{(5)}_{quH^3D^2}$	$(D_\mu H^\dagger H)(\bar{q}_pu_rD^\mu\tilde{H})$
$Q^{(6)}_{quH^3D^2}$	$(D_\mu H^\dagger H)(\bar{q}_p\sigma^{\mu\nu}u_rD_\nu\tilde{H})$
$Q^{(1)}_{qdH^3D^2}$	$(D_\mu H^\dagger H)(\bar{q}_pd_rH)$
$Q^{(2)}_{qdH^3D^2}$	$(D_\mu H^\dagger\tau^I D^\mu H)(\bar{q}_pd_r\tau^I H)$
$Q^{(3)}_{qdH^3D^2}$	$(D_\mu H^\dagger D_\nu H)(\bar{q}_p\sigma^{\mu\nu}d_rH)$
$Q^{(4)}_{qdH^3D^2}$	$(D_\mu H^\dagger\tau^I D_\nu H)(\bar{q}_p\sigma^{\mu\nu}d_r\tau^I H)$
$Q^{(5)}_{qdH^3D^2}$	$(H^\dagger D_\mu H)(\bar{q}_pd_rD^\mu H)$
$Q^{(6)}_{qdH^3D^2}$	$(H^\dagger D_\mu H)(\bar{q}_p\sigma^{\mu\nu}d_rD_\nu H)$

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

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

$Q^{(1)}_{lequH^2}$	$(\bar{l}_p e_r)(\bar{d}_s q_{tj})(H^\dagger H)$
$Q^{(2)}_{lequH^2}$	$(\bar{l}_p e_r)\tau^I(\bar{d}_s q_{tj})(H^\dagger \tau^I H)$
$Q_{l^2 udH^2}$	$(\bar{l}_p d_r H)(\widetilde{H}^\dagger \bar{u}_s l_t)$
$Q^{(5)}_{lequH^2}$	$(\bar{l}_p e_r H)(\widetilde{H}^\dagger \bar{u}_s q_t)$
$Q^{(5)}_{q^3 udH^2}$	$(\bar{q}_p d_r H)(\widetilde{H}^\dagger \bar{u}_s q_t)$
$Q^{(6)}_{q^3 udH^2}$	$(\bar{q}_p T^A d_r H)(\widetilde{H}^\dagger \bar{u}_s T^A q_t)$

$18(\bar{B}) : \psi^4 H^2 + \text{h.c.}$

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

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

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

$21(\bar{B}) : \psi^4 D^2 + \text{h.c.}$

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

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

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

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

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

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

$Q^{(1)}_{le^2 H^2}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{e}_s \gamma_\mu e_t)(H^\dagger H)$
$Q^{(2)}_{le^2 H^2}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{e}_s \gamma_\mu e_t)(H^\dagger \tau^I H)$
$Q^{(1)}_{lu^2 H^2}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{u}_s \gamma_\mu u_t)(H^\dagger H)$
$Q^{(2)}_{lu^2 H^2}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{u}_s \gamma_\mu u_t)(H^\dagger \tau^I H)$
$Q^{(1)}_{ld^2 H^2}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{d}_s \gamma_\mu d_t)(H^\dagger H)$
$Q^{(2)}_{ld^2 H^2}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{d}_s \gamma_\mu d_t)(H^\dagger \tau^I H)$
$Q^{(1)}_{q^2 u^2 H^2}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{e}_s \gamma_\mu e_t)(H^\dagger H)$
$Q^{(2)}_{q^2 u^2 H^2}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{e}_s \gamma_\mu e_t)(H^\dagger \tau^I H)$
$Q^{(3)}_{q^2 u^2 H^2}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{u}_s \gamma_\mu u_t)(H^\dagger H)$
$Q^{(4)}_{q^2 u^2 H^2}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma_\mu T^A u_t)(H^\dagger H)$
$Q^{(5)}_{q^2 u^2 H^2}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{u}_s \gamma_\mu T^A u_t)(H^\dagger \tau^I H)$
$Q^{(1)}_{q^2 d^2 H^2}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{d}_s \gamma_\mu d_t)(H^\dagger H)$
$Q^{(2)}_{q^2 d^2 H^2}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{d}_s \gamma_\mu d_t)(H^\dagger \tau^I H)$
$Q^{(3)}_{q^2 d^2 H^2}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma_\mu T^A d_t)(H^\dagger H)$
$Q^{(4)}_{q^2 d^2 H^2}$	$(\bar{q}_p \gamma^\mu \tau^I T^A q_r)(\bar{d}_s \gamma_\mu T^A d_t)(H^\dagger \tau^I H)$

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

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

SMEFT at $d = 8$: Murphy basis

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

$19 : (\bar{L}L)(\bar{L}L)X$

$Q^{(1)}_{lqqq}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{q}_s \gamma^\nu \tau^I q_t) W^I_{\mu\nu}$
$Q^{(2)}_{lqqq}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{q}_s \gamma^\nu \tau^I l_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{qqqG}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{q}_s \gamma^\nu T^A q_t) G^A_{\mu\nu}$
$Q^{(2)}_{qqqG}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{q}_s \gamma^\nu T^A q_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(3)}_{qqqG}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{q}_s \gamma^\nu T^A \tau^I q_t) G^A_{\mu\nu}$
$Q^{(4)}_{qqqG}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{q}_s \gamma^\nu T^A \tau^I q_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{qqqW}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{q}_s \gamma^\nu \tau^I q_t) W^I_{\mu\nu}$
$Q^{(2)}_{qqqW}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{q}_s \gamma^\nu \tau^I q_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(3)}_{qqqW}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{q}_s \gamma^\nu \tau^I q_t) W^I_{\mu\nu}$
$Q^{(4)}_{qqqW}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{q}_s \gamma^\nu \tau^I q_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{lequG}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{q}_s \gamma^\nu T^A q_t) G^A_{\mu\nu}$
$Q^{(2)}_{lequG}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{q}_s \gamma^\nu T^A q_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(3)}_{lequG}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{q}_s \gamma^\nu T^A \tau^I q_t) G^A_{\mu\nu}$
$Q^{(4)}_{lequG}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{q}_s \gamma^\nu T^A \tau^I q_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{lequW}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{q}_s \gamma^\nu \tau^I q_t) W^I_{\mu\nu}$
$Q^{(2)}_{lequW}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{q}_s \gamma^\nu \tau^I q_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(3)}_{lequW}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{q}_s \gamma^\nu q_t) W^I_{\mu\nu}$
$Q^{(4)}_{lequW}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{q}_s \gamma^\nu q_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{lequW}$	$\epsilon^{IJK} (\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{q}_s \gamma^\nu \tau^J q_t) W^K_{\mu\nu}$
$Q^{(2)}_{lequW}$	$\epsilon^{IJK} (\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{q}_s \gamma^\nu \tau^J q_t) \widetilde{W}^K_{\mu\nu}$
$Q^{(1)}_{lu^2B}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{u}_s \gamma^\nu q_t) B_{\mu\nu}$
$Q^{(2)}_{lu^2B}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{u}_s \gamma^\nu q_t) \widetilde{B}_{\mu\nu}$
$Q^{(3)}_{lu^2B}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{u}_s \gamma^\nu \tau^I q_t) B_{\mu\nu}$
$Q^{(4)}_{lu^2B}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{u}_s \gamma^\nu \tau^I q_t) \widetilde{B}_{\mu\nu}$
$Q^{(1)}_{ld^2B}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{d}_s \gamma^\nu q_t) B_{\mu\nu}$
$Q^{(2)}_{ld^2B}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{d}_s \gamma^\nu q_t) \widetilde{B}_{\mu\nu}$
$Q^{(3)}_{ld^2B}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{d}_s \gamma^\nu \tau^I q_t) B_{\mu\nu}$
$Q^{(4)}_{ld^2B}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{d}_s \gamma^\nu \tau^I q_t) \widetilde{B}_{\mu\nu}$
$Q^{(1)}_{qu^2B}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{u}_s \gamma^\nu u_t) B_{\mu\nu}$
$Q^{(2)}_{qu^2B}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{u}_s \gamma^\nu u_t) \widetilde{B}_{\mu\nu}$
$Q^{(3)}_{qu^2B}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{u}_s \gamma^\nu \tau^I u_t) B_{\mu\nu}$
$Q^{(4)}_{qu^2B}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{u}_s \gamma^\nu \tau^I u_t) \widetilde{B}_{\mu\nu}$
$Q^{(1)}_{qd^2B}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{d}_s \gamma^\nu d_t) B_{\mu\nu}$
$Q^{(2)}_{qd^2B}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{d}_s \gamma^\nu d_t) \widetilde{B}_{\mu\nu}$
$Q^{(3)}_{qd^2B}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{d}_s \gamma^\nu \tau^I d_t) B_{\mu\nu}$
$Q^{(4)}_{qd^2B}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{d}_s \gamma^\nu \tau^I d_t) \widetilde{B}_{\mu\nu}$

$19 : (\bar{R}R)(\bar{R}R)X$

$Q^{(1)}_{u^2G}$	$(\bar{u}_p \gamma^\mu u_r)(\bar{u}_s \gamma^\nu T^A u_t) G^A_{\mu\nu}$
$Q^{(2)}_{u^2G}$	$(\bar{u}_p \gamma^\mu u_r)(\bar{u}_s \gamma^\nu T^A u_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{d^2G}$	$(\bar{d}_p \gamma^\mu d_r)(\bar{d}_s \gamma^\nu T^A d_t) G^A_{\mu\nu}$
$Q^{(2)}_{d^2G}$	$(\bar{d}_p \gamma^\mu d_r)(\bar{d}_s \gamma^\nu T^A d_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{ud^2G}$	$(\bar{u}_p \gamma^\mu u_r)(\bar{d}_s \gamma^\nu T^A d_t) G^A_{\mu\nu}$
$Q^{(2)}_{ud^2G}$	$(\bar{u}_p \gamma^\mu u_r)(\bar{d}_s \gamma^\nu T^A d_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{u^2B}$	$(\bar{u}_p \gamma^\mu u_r)(\bar{u}_s \gamma^\nu u_t) B_{\mu\nu}$
$Q^{(2)}_{u^2B}$	$(\bar{u}_p \gamma^\mu u_r)(\bar{u}_s \gamma^\nu u_t) \widetilde{B}_{\mu\nu}$
$Q^{(1)}_{d^2B}$	$(\bar{d}_p \gamma^\mu d_r)(\bar{d}_s \gamma^\nu d_t) B_{\mu\nu}$
$Q^{(2)}_{d^2B}$	$(\bar{d}_p \gamma^\mu d_r)(\bar{d}_s \gamma^\nu d_t) \widetilde{B}_{\mu\nu}$
$Q^{(1)}_{ud^2B}$	$(\bar{u}_p \gamma^\mu u_r)(\bar{d}_s \gamma^\nu d_t) B_{\mu\nu}$
$Q^{(2)}_{ud^2B}$	$(\bar{u}_p \gamma^\mu u_r)(\bar{d}_s \gamma^\nu d_t) \widetilde{B}_{\mu\nu}$

$19 : (\bar{L}L)(\bar{R}R)X$

$Q^{(1)}_{le^2uW}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{e}_s \gamma^\nu e_t) W^I_{\mu\nu}$
$Q^{(2)}_{le^2uW}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{e}_s \gamma^\nu e_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{le^2uB}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{e}_s \gamma^\nu e_t) B_{\mu\nu}$
$Q^{(2)}_{le^2uB}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{e}_s \gamma^\nu e_t) \widetilde{B}_{\mu\nu}$
$Q^{(1)}_{lu^2G}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{u}_s \gamma^\nu T^A u_t) G^A_{\mu\nu}$
$Q^{(2)}_{lu^2G}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{u}_s \gamma^\nu T^A u_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{lu^2W}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{u}_s \gamma^\nu u_t) W^I_{\mu\nu}$
$Q^{(2)}_{lu^2W}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{u}_s \gamma^\nu u_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{lu^2B}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{u}_s \gamma^\nu u_t) B_{\mu\nu}$
$Q^{(2)}_{lu^2B}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{u}_s \gamma^\nu u_t) \widetilde{B}_{\mu\nu}$
$Q^{(1)}_{ld^2G}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{d}_s \gamma^\nu T^A d_t) G^A_{\mu\nu}$
$Q^{(2)}_{ld^2G}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{d}_s \gamma^\nu T^A d_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{ld^2W}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{d}_s \gamma^\nu d_t) W^I_{\mu\nu}$
$Q^{(2)}_{ld^2W}$	$(\bar{l}_p \gamma^\mu \tau^I l_r)(\bar{d}_s \gamma^\nu d_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{ld^2B}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{d}_s \gamma^\nu d_t) B_{\mu\nu}$
$Q^{(2)}_{ld^2B}$	$(\bar{l}_p \gamma^\mu l_r)(\bar{d}_s \gamma^\nu d_t) \widetilde{B}_{\mu\nu}$
$Q^{(1)}_{qe^2uG}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{e}_s \gamma^\nu e_t) G^A_{\mu\nu}$
$Q^{(2)}_{qe^2uG}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{e}_s \gamma^\nu e_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(1)}_{qe^2uW}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{e}_s \gamma^\nu e_t) W^I_{\mu\nu}$
$Q^{(2)}_{qe^2uW}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{e}_s \gamma^\nu e_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{qe^2uB}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{e}_s \gamma^\nu e_t) B_{\mu\nu}$
$Q^{(2)}_{qe^2uB}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{e}_s \gamma^\nu e_t) \widetilde{B}_{\mu\nu}$
$Q^{(1)}_{qu^2G}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{u}_s \gamma^\nu T^A u_t) G^A_{\mu\nu}$
$Q^{(2)}_{qu^2G}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{u}_s \gamma^\nu T^A u_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(3)}_{qu^2G}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma^\nu u_t) G^A_{\mu\nu}$
$Q^{(4)}_{qu^2G}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma^\nu u_t) \widetilde{G}^A_{\mu\nu}$

$19 : (\bar{L}L)(\bar{R}R)X$

$Q^{(5)}_{qu^2G}$	$f^{ABC} (\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma^\nu T^B u_t) G^C_{\mu\nu}$
$Q^{(6)}_{qu^2G}$	$f^{ABC} (\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma^\nu T^B u_t) \widetilde{G}^C_{\mu\nu}$
$Q^{(7)}_{qu^2G}$	$d^{ABC} (\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma^\nu T^B u_t) G^C_{\mu\nu}$
$Q^{(8)}_{qu^2G}$	$d^{ABC} (\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma^\nu T^B u_t) \widetilde{G}^C_{\mu\nu}$
$Q^{(1)}_{qu^2W}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{u}_s \gamma^\nu u_t) W^I_{\mu\nu}$
$Q^{(2)}_{qu^2W}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{u}_s \gamma^\nu u_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(3)}_{qu^2W}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma^\nu u_t) W^I_{\mu\nu}$
$Q^{(4)}_{qu^2W}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma^\nu u_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{qu^2B}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{u}_s \gamma^\nu u_t) B_{\mu\nu}$
$Q^{(2)}_{qu^2B}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{u}_s \gamma^\nu u_t) \widetilde{B}_{\mu\nu}$
$Q^{(3)}_{qu^2B}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma^\nu T^A u_t) B_{\mu\nu}$
$Q^{(4)}_{qu^2B}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{u}_s \gamma^\nu T^A u_t) \widetilde{B}_{\mu\nu}$
$Q^{(1)}_{qd^2G}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{d}_s \gamma^\nu d_t) B_{\mu\nu}$
$Q^{(2)}_{qd^2G}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{d}_s \gamma^\nu d_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(3)}_{qd^2G}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma^\nu d_t) G^A_{\mu\nu}$
$Q^{(4)}_{qd^2G}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma^\nu d_t) \widetilde{G}^A_{\mu\nu}$
$Q^{(5)}_{qd^2G}$	$f^{ABC} (\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma^\nu T^B d_t) G^C_{\mu\nu}$
$Q^{(6)}_{qd^2G}$	$f^{ABC} (\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma^\nu T^B d_t) \widetilde{G}^C_{\mu\nu}$
$Q^{(7)}_{qd^2G}$	$d^{ABC} (\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma^\nu T^B d_t) G^C_{\mu\nu}$
$Q^{(8)}_{qd^2G}$	$d^{ABC} (\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma^\nu T^B d_t) \widetilde{G}^C_{\mu\nu}$
$Q^{(1)}_{qd^2W}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{d}_s \gamma^\nu d_t) W^I_{\mu\nu}$
$Q^{(2)}_{qd^2W}$	$(\bar{q}_p \gamma^\mu \tau^I q_r)(\bar{d}_s \gamma^\nu d_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(3)}_{qd^2W}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma^\nu d_t) W^I_{\mu\nu}$
$Q^{(4)}_{qd^2W}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma^\nu d_t) \widetilde{W}^I_{\mu\nu}$
$Q^{(1)}_{qd^2B}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{d}_s \gamma^\nu d_t) B_{\mu\nu}$
$Q^{(2)}_{qd^2B}$	$(\bar{q}_p \gamma^\mu q_r)(\bar{d}_s \gamma^\nu d_t) \widetilde{B}_{\mu\nu}$
$Q^{(3)}_{qd^2B}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma^\nu T^A d_t) B_{\mu\nu}$
$Q^{(4)}_{qd^2B}$	$(\bar{q}_p \gamma^\mu T^A q_r)(\bar{d}_s \gamma^\nu T^A d_t) \widetilde{B}_{\mu\nu}$

SMEFT at $d = 8$: Murphy basis

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

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

$\mathbf{19(\bar{B}) : \psi^4 X + h.c.}$	
$Q^{(1)}_{lqudG}$	$(T^A)^k_l \epsilon_{ik\alpha\beta} \epsilon_{jk} (d^{\alpha}_p C\sigma^{\mu\nu} u^{\beta}_r)(q^{i\gamma}_s C l^j_t) G^A_{\mu\nu}$
$Q^{(2)}_{lqudG}$	$(T^A)^k_l \epsilon_{ik\alpha\beta} \epsilon_{jk} (d^{\alpha}_p C u^{\beta}_r)(q^{i\gamma}_s C\sigma^{\mu\nu} l^j_t) G^A_{\mu\nu}$
$Q^{(3)}_{lqudG}$	$(T^A)^k_{(a} \epsilon_{\beta\gamma\delta)} \epsilon_{jk} (d^{\alpha}_p C\sigma^{\mu\nu} u^{\beta}_r)(q^{i\gamma}_s C l^k_t) G^A_{\mu\nu}$
$Q^{(4)}_{lqudG}$	$(T^A)^k_{(a} \epsilon_{\beta\gamma\delta)} \epsilon_{jk} (d^{\alpha}_p C u^{\beta}_r)(q^{i\gamma}_s C\sigma^{\mu\nu} l^k_t) G^A_{\mu\nu}$
$Q^{(1)}_{lqudW}$	$\epsilon_{\alpha\beta\gamma} (\tau^I \epsilon)_{jk} (d^{\alpha}_p C\sigma^{\mu\nu} u^{\beta}_r)(q^{i\gamma}_s C l^j_t) W^I_{\mu\nu}$
$Q^{(2)}_{lqudW}$	$\epsilon_{\alpha\beta\gamma} (\tau^I \epsilon)_{jk} (d^{\alpha}_p C u^{\beta}_r)(q^{i\gamma}_s C\sigma^{\mu\nu} l^j_t) W^I_{\mu\nu}$
$Q^{(1)}_{lqudB}$	$\epsilon_{\alpha\beta\gamma} \epsilon_{jk} (d^{\alpha}_p C\sigma^{\mu\nu} u^{\beta}_r)(q^{i\gamma}_s C l^j_t) B_{\mu\nu}$
$Q^{(2)}_{lqudB}$	$\epsilon_{\alpha\beta\gamma} \epsilon_{jk} (d^{\alpha}_p C u^{\beta}_r)(q^{i\gamma}_s C\sigma^{\mu\nu} l^j_t) B_{\mu\nu}$
$Q^{(1)}_{eq^2uG}$	$(T^A)^k_l \epsilon_{ka\beta\gamma} \epsilon_{ij} (q^{i\alpha}_p C\sigma^{\mu\nu} q^{j\beta}_r)(u^{\gamma}_s C e_t) G^A_{\mu\nu}$
$Q^{(2)}_{eq^2uG}$	$(T^A)^k_{(a} \epsilon_{\beta)\gamma\delta} \epsilon_{ij} (q^{i\alpha}_p C q^{j\beta}_r)(u^{\gamma}_s C\sigma^{\mu\nu} e_t) G^A_{\mu\nu}$
$Q^{(1)}_{eq^2uW}$	$\epsilon_{\alpha\beta\gamma} (\tau^I \epsilon)_{jk} (q^{i\alpha}_p C\sigma^{\mu\nu} q^{k\beta}_r)(u^{\gamma}_s C e_t) W^I_{\mu\nu}$
$Q^{(2)}_{eq^2uB}$	$\epsilon_{\alpha\beta\gamma} \epsilon_{ij} (q^{i\alpha}_p C q^{j\beta}_r)(u^{\gamma}_s C e_t) B_{\mu\nu}$
$Q^{(1)}_{lq^3G}$	$(T^A)^k_l \epsilon_{ik\alpha\beta} \epsilon_{mn} \epsilon_{jk} (q^{i\alpha}_p C\sigma^{\mu\nu} q^{j\beta}_r)(q^{k\gamma}_s C l^m_t) G^A_{\mu\nu}$
$Q^{(2)}_{lq^3G}$	$(T^A)^k_{(a} \epsilon_{\beta)\gamma\delta} \epsilon_{mn} \epsilon_{jk} (q^{i\alpha}_p C q^{j\beta}_r)(q^{k\gamma}_s C\sigma^{\mu\nu} l^m_t) G^A_{\mu\nu}$
$Q^{(1)}_{lq^3W}$	$\epsilon_{\alpha\beta\gamma} (\tau^I)_{mn} \epsilon_{jk} (q^{i\alpha}_p C q^{j\beta}_r)(q^{k\gamma}_s C\sigma^{\mu\nu} l^m_t) W^I_{\mu\nu}$
$Q^{(2)}_{lq^3W}$	$\epsilon_{\alpha\beta\gamma} (\tau^I)_{mj} \epsilon_{kn} (q^{i\alpha}_p C\sigma^{\mu\nu} q^{j\beta}_r)(q^{k\gamma}_s C l^n_t) W^I_{\mu\nu}$
$Q^{(1)}_{lq^3B}$	$\epsilon_{\alpha\beta\gamma} \epsilon_{mn} \epsilon_{jk} (q^{i\alpha}_p C q^{j\beta}_r)(q^{k\gamma}_s C\sigma^{\mu\nu} l^n_t) B_{\mu\nu}$
$Q^{(1)}_{eu^3dG}$	$(T^A)^k_l \epsilon_{ka\beta} (d^{\alpha}_p C\sigma^{\mu\nu} u^{\beta}_r)(u^{\gamma}_s C e_t) G^A_{\mu\nu}$
$Q^{(2)}_{eu^3dG}$	$(T^A)^k_l \epsilon_{ka\beta} (u^{\alpha}_p C\sigma^{\mu\nu} u^{\beta}_r)(d^{\gamma}_s C e_t) G^A_{\mu\nu}$
$Q^{(3)}_{eu^3dG}$	$(T^A)^k_{(a} \epsilon_{\beta)\gamma\delta} (u^{\alpha}_p C u^{\beta}_r)(d^{\gamma}_s C\sigma^{\mu\nu} e_t) G^A_{\mu\nu}$
$Q^{(1)}_{eu^3dB}$	$\epsilon_{\alpha\beta\gamma} (d^{\alpha}_p C\sigma^{\mu\nu} u^{\beta}_r)(u^{\gamma}_s C e_t) B_{\mu\nu}$
$Q^{(2)}_{eu^3dB}$	$\epsilon_{\alpha\beta\gamma} (u^{\alpha}_p C\sigma^{\mu\nu} u^{\beta}_r)(d^{\gamma}_s C e_t) B_{\mu\nu}$
$Q^{(2)}_{eq^2uW}$	$\epsilon_{\alpha\beta\gamma} (\tau^I \epsilon)_{jk} (q^{i\alpha}_p C q^{k\beta}_r)(u^{\gamma}_s C\sigma^{\mu\nu} e_t) W^I_{\mu\nu}$
$Q^{(2)}_{eq^2uB}$	$\epsilon_{\alpha\beta\gamma} \epsilon_{jk} (q^{i\alpha}_p C\sigma^{\mu\nu} q^{k\beta}_r)(u^{\gamma}_s C e_t) B_{\mu\nu}$
$Q^{(3)}_{lq^3G}$	$(T^A)^k_{(a} \epsilon_{\beta)\gamma\delta} \epsilon_{mn} \epsilon_{jk} (q^{i\alpha}_p C\sigma^{\mu\nu} q^{j\beta}_r)(q^{k\gamma}_s C l^m_t) G^A_{\mu\nu}$
$Q^{(4)}_{lq^3G}$	$(T^A)^k_l \epsilon_{ik\alpha\beta} \epsilon_{mn} \epsilon_{jk} (q^{i\alpha}_p C q^{j\beta}_r)(q^{k\gamma}_s C\sigma^{\mu\nu} l^m_t) G^A_{\mu\nu}$
$Q^{(3)}_{lq^3W}$	$\epsilon_{\alpha\beta\gamma} \epsilon_{mn} (\sigma^I)_{jk} (q^{i\alpha}_p C q^{j\beta}_r)(q^{k\gamma}_s C\sigma^{\mu\nu} l^n_t) W^I_{\mu\nu}$
$Q^{(2)}_{lq^3B}$	$\epsilon_{\alpha\beta\gamma} \epsilon_{mn} \epsilon_{jk} (q^{i\alpha}_p C\sigma^{\mu\nu} q^{j\beta}_r)(q^{k\gamma}_s C l^n_t) B_{\mu\nu}$

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

SMEFT at $d = 8$: Murphy basis

$\mathbf{20}: \psi^4 HD + \text{h.c.}$	
$Q^{(1)}_{\ell^2 eHD}$	$i(\bar{l}_p\gamma^\mu l_r)(\bar{l}_s e_t)D_\mu H]$
$Q^{(2)}_{\ell^2 eHD}$	$i(\bar{l}_p\gamma^\mu\tau^I l_r)(\bar{l}_s e_t)\tau^I D_\mu H]$
$Q^{(3)}_{\ell^2 eHD}$	$i(\bar{l}_p\gamma^\mu l_r)([D_\mu\bar{l}_s]e_t)H]$
$Q^{(1)}_{\ell e^2 HD}$	$i(\bar{e}_p\gamma^\mu e_r)([\bar{l}_s D_\mu e_t)H]$
$Q^{(1)}_{\ell eq^2 HD}$	$i(\bar{q}_p\gamma^\mu q_r)([\bar{l}_s e_t)D_\mu H]$
$Q^{(2)}_{\ell eq^2 HD}$	$i(\bar{l}_p\gamma^\mu q_r^a)[(\bar{q}_{sa}e_t)D_\mu H]$
$Q^{(3)}_{\ell eq^2 HD}$	$i(\bar{q}_p\gamma^\mu\tau^I q_r)([\bar{l}_s e_t)\tau^I D_\mu H]$
$Q^{(4)}_{\ell eq^2 HD}$	$i(\bar{l}_p\gamma^\mu\tau^I q_r^a)[(\bar{q}_{sa}e_t)\tau^I D_\mu H]$
$Q^{(5)}_{\ell eq^2 HD}$	$i(\bar{q}_p\gamma^\mu q_r)([\bar{l}_s D_\mu e_t)H]$
$Q^{(6)}_{\ell eq^2 HD}$	$i(\bar{q}_p\gamma^\nu\tau^I q_r)([\bar{l}_s D_\mu e_t)\tau^I H]$
$Q^{(1)}_{\ell eu^2 HD}$	$i(\bar{u}_p\gamma^\mu u_r)([\bar{l}_s e_t)D_\mu H]$
$Q^{(2)}_{\ell eu^2 HD}$	$i(\bar{u}_{pa}\gamma^\mu e_r)([\bar{l}_s u_t^a)D_\mu H]$
$Q^{(3)}_{\ell eu^2 HD}$	$i(\bar{u}_p\gamma^\mu u_r)([D_\mu\bar{l}_s]e_t)H]$
$Q^{(1)}_{\ell ed^2 HD}$	$i(\bar{d}_p\gamma^\mu d_r)([\bar{l}_s e_t)D_\mu H]$
$Q^{(2)}_{\ell ed^2 HD}$	$i(\bar{d}_{pa}\gamma^\mu e_r)([\bar{l}_s d_t^a)D_\mu H]$
$Q^{(3)}_{\ell ed^2 HD}$	$i(\bar{d}_p\gamma^\mu d_r)([D_\mu\bar{l}_s]e_t)H]$
$Q^{(1)}_{\ell equHD}$	$i\epsilon_{jk}(\bar{u}_p\gamma^\mu d_r)(\bar{e}_s l_t^j)D_\mu H^k$
$Q^{(2)}_{\ell equHD}$	$i\epsilon_{jk}[\bar{e}_p\gamma^\mu d_r^a)(\bar{u}_{sa}l_t^j)D_\mu H^k$
$Q^{(3)}_{\ell equHD}$	$i\epsilon_{jk}(\bar{u}_p\gamma^\mu d_r)(\bar{e}_s D_\mu l_t^j)H^k$
$Q^{(3)}_{\ell e^3 HD}$	$i(\bar{e}_p\gamma^\mu e_r)([\bar{l}_s e_t)D_\mu H]$

$\mathbf{20}: \psi^4 HD + \text{h.c.}$	
$Q^{(1)}_{\ell^2 quHD}$	$i(\bar{l}_p\gamma^\mu l_r)([\bar{q}_s u_t)D_\mu\tilde{H}]$
$Q^{(2)}_{\ell^2 quHD}$	$i(\bar{q}_{pa}\gamma^\mu l_r)([\bar{l}_s u_t^a)D_\mu\tilde{H}]$
$Q^{(3)}_{\ell^2 quHD}$	$i(\bar{l}_p\gamma^\mu\tau^I l_r)([\bar{q}_s u_t)\tau^I D_\mu\tilde{H}]$
$Q^{(4)}_{\ell^2 quHD}$	$i(\bar{q}_{pa}\gamma^\mu\tau^I l_r)([\bar{l}_s u_t^a)\tau^I D_\mu\tilde{H}]$
$Q^{(5)}_{\ell^2 quHD}$	$i(\bar{l}_p\gamma^\mu l_r)([\bar{q}_s D_\mu u_t)\tilde{H}]$
$Q^{(6)}_{\ell^2 quHD}$	$i(\bar{l}_p\gamma^\mu\tau^I l_r)([\bar{q}_s D_\mu u_t)\tau^I\tilde{H}]$
$Q^{(1)}_{e^2 quHD}$	$i(\bar{e}_p\gamma^\mu e_r)([\bar{q}_s u_t)D_\mu\tilde{H}]$
$Q^{(2)}_{e^2 quHD}$	$i(\bar{e}_p\gamma^\mu q_s^a)([\bar{q}_{sa}e_t)D_\mu\tilde{H}]$
$Q^{(3)}_{e^2 quHD}$	$i(\bar{e}_p\gamma^\mu e_r)([D_\mu\bar{q}_s u_t)\tilde{H}]$
$Q^{(1)}_{q^2 uHD}$	$i(\bar{q}_p\gamma^\mu q_r)([\bar{q}_s u_t)D_\mu\tilde{H}]$
$Q^{(2)}_{q^2 uHD}$	$i(\bar{q}_p\gamma^\mu\tau^I q_r)([\bar{q}_s u_t)\tau^I D_\mu\tilde{H}]$
$Q^{(3)}_{q^2 uHD}$	$i(\bar{q}_p\gamma^\mu T^A q_r)([\bar{q}_s T^A u_t)D_\mu\tilde{H}]$
$Q^{(4)}_{q^2 uHD}$	$i(\bar{q}_p\gamma^\mu T^A\tau^I q_r)([\bar{q}_s T^A u_t)\tau^I D_\mu\tilde{H}]$
$Q^{(5)}_{q^2 uHD}$	$i(\bar{q}_p\gamma^\mu q_r)([D_\mu\bar{q}_s u_t)\tilde{H}]$
$Q^{(6)}_{q^2 uHD}$	$i(\bar{q}_p\gamma^\mu\tau^I q_r)([D_\mu\bar{q}_s u_t)\tau^I\tilde{H}]$
$Q^{(7)}_{q^2 uHD}$	$i(\bar{q}_p\gamma^\mu T^A q_r)([D_\mu\bar{q}_s T^A u_t)\tilde{H}]$
$Q^{(8)}_{q^2 uHD}$	$i(\bar{q}_p\gamma^\mu T^A\tau^I q_r)([D_\mu\bar{q}_s T^A u_t)\tau^I\tilde{H}]$
$Q^{(1)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu q_r)([\bar{q}_s d_t)D_\mu\tilde{H}]$
$Q^{(2)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu\tau^I q_r)([\bar{q}_s d_t)\tau^I D_\mu\tilde{H}]$
$Q^{(3)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu T^A q_r)([\bar{q}_s T^A d_t)D_\mu\tilde{H}]$
$Q^{(4)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu T^A\tau^I q_r)([\bar{q}_s T^A d_t)\tau^I D_\mu\tilde{H}]$
$Q^{(5)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu q_r)([D_\mu\bar{q}_s d_t)\tilde{H}]$
$Q^{(6)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu\tau^I q_r)([D_\mu\bar{q}_s d_t)\tau^I\tilde{H}]$
$Q^{(7)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu T^A q_r)([D_\mu\bar{q}_s T^A d_t)\tilde{H}]$
$Q^{(8)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu T^A\tau^I q_r)([D_\mu\bar{q}_s T^A d_t)\tau^I\tilde{H}]$

$\mathbf{20}: \psi^4 HD + \text{h.c.}$	
$Q^{(1)}_{\ell^2 qdHD}$	$i(\bar{l}_p\gamma^\mu l_r)([\bar{q}_s d_t)D_\mu H]$
$Q^{(2)}_{\ell^2 qdHD}$	$i(\bar{q}_{pa}\gamma^\mu l_r)([\bar{l}_s d_t^a)D_\mu H]$
$Q^{(3)}_{\ell^2 qdHD}$	$i(\bar{l}_p\gamma^\mu\tau^I l_r)([\bar{q}_s d_t)\tau^I D_\mu H]$
$Q^{(4)}_{\ell^2 qdHD}$	$i(\bar{q}_{pa}\gamma^\mu\tau^I l_r)([\bar{l}_s d_t^a)\tau^I D_\mu H]$
$Q^{(5)}_{\ell^2 qdHD}$	$i(\bar{l}_p\gamma^\mu l_r)([\bar{q}_s D_\mu d_t)H]$
$Q^{(6)}_{\ell^2 qdHD}$	$i(\bar{l}_p\gamma^\mu\tau^I l_r)([\bar{q}_s D_\mu d_t)\tau^I H]$
$Q^{(1)}_{e^2 qdHD}$	$i(\bar{e}_p\gamma^\mu e_r)([\bar{q}_s d_t)D_\mu H]$
$Q^{(2)}_{e^2 qdHD}$	$i(\bar{e}_p\gamma^\mu q_s^a)([\bar{q}_{sa}e_t)D_\mu H]$
$Q^{(3)}_{e^2 qdHD}$	$i(\bar{e}_p\gamma^\mu e_r)([D_\mu\bar{q}_s d_t)H]$
$Q^{(1)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu q_r)([\bar{q}_s d_t)D_\mu H]$
$Q^{(2)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu\tau^I q_r)([\bar{q}_s d_t)\tau^I D_\mu H]$
$Q^{(3)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu T^A q_r)([\bar{q}_s T^A d_t)D_\mu H]$
$Q^{(4)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu T^A\tau^I q_r)([\bar{q}_s T^A d_t)\tau^I D_\mu H]$
$Q^{(5)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu q_r)([D_\mu\bar{q}_s d_t)H]$
$Q^{(6)}_{q^2 dHD}$	$i(\bar{q}_p\gamma^\mu\tau^I q_r)([D_\mu\bar{q}_s d_t)\tau^I H]$
$Q^{(1)}_{qu^2 dHD}$	$i(\bar{u}_p\gamma^\mu d_r)([\bar{q}_s u_t)D_\mu H]$
$Q^{(2)}_{qu^2 dHD}$	$i(\bar{q}_p\gamma^\mu d_r)([\bar{q}_s u_t^a)D_\mu H]$
$Q^{(3)}_{qu^2 dHD}$	$i(\bar{u}_p\gamma^\mu u_r)([\bar{q}_s T^A d_t)D_\mu H]$
$Q^{(4)}_{qu^2 dHD}$	$i(\bar{u}_p\gamma^\mu T^A u_r)([\bar{q}_s T^A d_t)D_\mu H]$
$Q^{(5)}_{qu^2 dHD}$	$i(\bar{u}_p\gamma^\mu u_r)([D_\mu\bar{q}_s d_t)H]$
$Q^{(6)}_{qu^2 dHD}$	$i(\bar{u}_p\gamma^\mu T^A u_r)([D_\mu\bar{q}_s T^A d_t)H]$
$Q^{(1)}_{qd^2 HD}$	$i(\bar{d}_p\gamma^\mu d_r)([\bar{q}_s d_t)D_\mu H]$
$Q^{(2)}_{qd^3 HD}$	$i(\bar{d}_p\gamma^\mu d_r)([\bar{q}_s D_\mu d_t)H]$
$Q^{(3)}_{qd^3 HD}$	$i(\bar{d}_p\gamma^\mu T^A d_r)([\bar{q}_s T^A d_t)D_\mu H]$
	$i(\bar{d}_p\gamma^\mu d_r)([\bar{q}_s D_\mu d_t)H]$

$\mathbf{20}(\not{B}): \psi^4 HD + \text{h.c.}$	
$Q^{(1)}_{lu^2 dHD}$	$i\epsilon_{\alpha\beta\gamma}[D_\mu H^\dagger(u_p^\alpha C\gamma^\mu l_r)](u_s^\beta C d_t^\gamma)$
$Q^{(2)}_{lu^2 dHD}$	$i\epsilon_{\alpha\beta\gamma}[H^\dagger(u_p^\alpha C\gamma^\mu l_r)](D_\mu u_s^\beta C d_t^\gamma)$
$Q^{(1)}_{lud^2 HD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(d_p^\alpha C\gamma^\mu l_r^j)(d_s^\beta C u_t^\gamma)D_\mu H^k$
$Q^{(2)}_{lud^2 HD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(d_p^\alpha C\gamma^\mu l_r^j)(D_\mu d_s^\beta C u_t^\gamma)H^k$
$Q^{(1)}_{lq^2 uHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jn}\epsilon_{km}D_\mu H^{n\dagger}(q_p^{m\alpha}C\gamma^\mu u_r^\beta)(q_s^{\gamma k}Cl_t^j)$
$Q^{(2)}_{lq^2 uHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{kn}\epsilon_{jm}D_\mu H^{n\dagger}(q_p^{m\alpha}C\gamma^\mu u_r^\beta)(q_s^{\gamma j}Cl_t^k)$
$Q^{(3)}_{lq^2 uHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jn}\epsilon_{km}H^{n\dagger}(q_p^{m\alpha}C\gamma^\mu u_r^\beta)(D_\mu q_s^{\gamma j}Cl_t^k)$
$Q^{(1)}_{lq^2 dHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jn}\epsilon_{km}(q_p^{m\alpha}C\gamma^\mu d_r^\beta)(q_s^{\gamma j}Cl_t^k)D_\mu H^n$
$Q^{(2)}_{lq^2 dHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{kn}\epsilon_{jm}(q_p^{m\alpha}C\gamma^\mu d_r^\beta)(q_s^{\gamma j}Cl_t^k)D_\mu H^n$
$Q^{(3)}_{lq^2 dHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jn}\epsilon_{km}(q_p^{m\alpha}C\gamma^\mu d_r^\beta)(D_\mu q_s^{\gamma j}Cl_t^k)H^n$
$Q_{eq^3 HD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{mn}\epsilon_{jk}(q_p^{i\alpha}C\gamma^\mu e_r)(D_\mu q_s^{k\beta}Cq_t^{m\gamma})H^n$
$Q^{(1)}_{equ^2 HD}$	$i\epsilon_{\alpha\beta\gamma}[D_\mu H^\dagger(u_p^\alpha C\gamma^\mu q_r^\beta)](u_s^\gamma Ce_t)$
$Q^{(2)}_{equ^2 HD}$	$i\epsilon_{\alpha\beta\gamma}[H^\dagger(u_p^\alpha C\gamma^\mu q_r^\beta)](D_\mu u_s^\gamma Ce_t)$
$Q^{(1)}_{equdHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(q_p^{i\alpha}C\gamma^\mu u_r^\beta)(d_s^\gamma Ce_t)D_\mu H^k$
$Q^{(2)}_{equdHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(q_p^{i\alpha}C\gamma^\mu d_r^\beta)(u_s^\gamma Ce_t)D_\mu H^k$
$Q^{(3)}_{equdHD}$	$i\epsilon_{\alpha\beta\gamma}\epsilon_{jk}(q_p^{i\alpha}C\gamma^\mu u_r^\beta)(d_s^\gamma CD_\mu e_t)H^k$

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

SMEFT at $d = 8$: Murphy basis

$\mathbf{21}: (\bar{L}L)(\bar{L}L)D^2$	
$Q^{(1)}_{\ell^4 D^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\ell_r)D_\nu(\overline{\ell}_s\gamma_\mu\ell_t)$
$Q^{(2)}_{\ell^4 D^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^\nu\ell_r)(\overline{\ell}_s\gamma_\mu\overleftrightarrow{D}_\nu\ell_t)$
$Q^{(1)}_{q^4 D^2}$	$D^\nu(\overline{q}_p\gamma^\mu q_r)D_\nu(\overline{q}_s\gamma_\mu q_t)$
$Q^{(2)}_{q^4 D^2}$	$(\overline{q}_p\gamma^\mu\overleftrightarrow{D}^\nu q_r)(\overline{q}_s\gamma_\mu\overleftrightarrow{D}_\nu q_t)$
$Q^{(3)}_{q^4 D^2}$	$D^\nu(\overline{q}_p\gamma^\mu\tau^I q_r)D_\nu(\overline{q}_s\gamma_\mu\tau^I q_t)$
$Q^{(4)}_{q^4 D^2}$	$(\overline{q}_p\gamma^\mu\overleftrightarrow{D}^{I\nu}q_r)(\overline{q}_s\gamma_\mu\overleftrightarrow{D}^I_\nu q_t)$
$Q^{(1)}_{\ell q^3 D^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\ell_r)D_\nu(\overline{q}_s\gamma_\mu q_t)$
$Q^{(2)}_{\ell q^3 D^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^\nu\ell_r)(\overline{q}_s\gamma_\mu\overleftrightarrow{D}_\nu q_t)$
$Q^{(3)}_{\ell q^3 D^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\tau^I\ell_r)D_\nu(\overline{q}_s\gamma_\mu\tau^I q_t)$
$Q^{(4)}_{\ell q^3 D^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^{I\nu}\ell_r)(\overline{q}_s\gamma_\mu\overleftrightarrow{D}^I_\nu q_t)$

$\mathbf{21}: (\bar{R}R)(\bar{R}R)D^2$	
$Q_{e^4 D^2}$	$D^\nu(\overline{e}_p\gamma^\mu e_r)D_\nu(\overline{e}_s\gamma_\mu e_t)$
$Q^{(1)}_{u^4 D^2}$	$D^\nu(\overline{u}_p\gamma^\mu u_r)D_\nu(\overline{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{u^4 D^2}$	$(\overline{u}_p\gamma^\mu\overleftrightarrow{D}^\nu u_r)(\overline{u}_s\gamma_\mu\overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{d^4 D^2}$	$D^\nu(\overline{d}_p\gamma^\mu d_r)D_\nu(\overline{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{d^4 D^2}$	$(\overline{d}_p\gamma^\mu\overleftrightarrow{D}^\nu d_r)(\overline{d}_s\gamma_\mu\overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{e^2u^2 D^2}$	$D^\nu(\overline{e}_p\gamma^\mu e_r)D_\nu(\overline{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{e^2u^2 D^2}$	$(\overline{e}_p\gamma^\mu\overleftrightarrow{D}^\nu e_r)(\overline{u}_s\gamma_\mu\overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{e^2d^2 D^2}$	$D^\nu(\overline{e}_p\gamma^\mu e_r)D_\nu(\overline{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{e^2d^2 D^2}$	$(\overline{e}_p\gamma^\mu\overleftrightarrow{D}^\nu e_r)(\overline{d}_s\gamma_\mu\overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{u^2d^2 D^2}$	$D^\nu(\overline{u}_p\gamma^\mu u_r)D_\nu(\overline{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{u^2d^2 D^2}$	$(\overline{u}_p\gamma^\mu\overleftrightarrow{D}^\nu u_r)(\overline{d}_s\gamma_\mu\overleftrightarrow{D}_\nu d_t)$
$Q^{(3)}_{u^2d^2 D^2}$	$D^\nu(\overline{u}_p\gamma^\mu T^A u_r)D_\nu(\overline{d}_s\gamma_\mu T^A d_t)$
$Q^{(4)}_{u^2d^2 D^2}$	$(\overline{u}_p\gamma^\mu T^A\overleftrightarrow{D}^\nu u_r)(\overline{d}_s\gamma_\mu T^A\overleftrightarrow{D}_\nu d_t)$

$\mathbf{21}: (\bar{L}L)(\bar{R}R)D^2$	
$Q^{(1)}_{\ell e^2 D^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\ell_r)D_\nu(\overline{e}_s\gamma_\mu e_t)$
$Q^{(2)}_{\ell e^2 D^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^\nu\ell_r)(\overline{e}_s\gamma_\mu\overleftrightarrow{D}_\nu e_t)$
$Q^{(1)}_{\ell u^2 D^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\ell_r)D_\nu(\overline{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{\ell u^2 D^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^\nu\ell_r)(\overline{u}_s\gamma_\mu\overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{\ell d^2 D^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\ell_r)D_\nu(\overline{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{\ell d^2 D^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^\nu\ell_r)(\overline{d}_s\gamma_\mu\overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{q e^2 D^2}$	$D^\nu(\overline{q}_p\gamma^\mu q_r)D_\nu(\overline{e}_s\gamma_\mu e_t)$
$Q^{(2)}_{q e^2 D^2}$	$(\overline{q}_p\gamma^\mu\overleftrightarrow{D}^\nu q_r)(\overline{e}_s\gamma_\mu\overleftrightarrow{D}_\nu e_t)$
$Q^{(1)}_{q u^2 D^2}$	$D^\nu(\overline{q}_p\gamma^\mu q_r)D_\nu(\overline{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{q u^2 D^2}$	$(\overline{q}_p\gamma^\mu\overleftrightarrow{D}^\nu q_r)(\overline{u}_s\gamma_\mu\overleftrightarrow{D}_\nu u_t)$
$Q^{(3)}_{q u^2 D^2}$	$D^\nu(\overline{q}_p\gamma^\mu T^A q_r)D_\nu(\overline{u}_s\gamma_\mu T^A u_t)$
$Q^{(4)}_{q u^2 D^2}$	$(\overline{q}_p\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)(\overline{u}_s\gamma_\mu T^A\overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{q d^2 D^2}$	$D^\nu(\overline{q}_p\gamma^\mu q_r)D_\nu(\overline{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{q d^2 D^2}$	$(\overline{q}_p\gamma^\mu\overleftrightarrow{D}^\nu q_r)(\overline{d}_s\gamma_\mu\overleftrightarrow{D}_\nu d_t)$
$Q^{(3)}_{q d^2 D^2}$	$D^\nu(\overline{q}_p\gamma^\mu T^A q_r)D_\nu(\overline{d}_s\gamma_\mu T^A d_t)$
$Q^{(4)}_{q d^2 D^2}$	$(\overline{q}_p\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)(\overline{d}_s\gamma_\mu T^A\overleftrightarrow{D}_\nu d_t)$

$\mathbf{21}: (\bar{L}R)(\bar{L}R)D^2 + \text{h.c.}$	
$Q^{(1)}_{\ell^2 u d D^2}$	$D_\mu(\overline{\ell}^c_p u_r)\epsilon_{jk}D^\mu(\overline{q}^k_s d_t)$
$Q^{(2)}_{\ell^2 u d D^2}$	$D_\mu(\overline{\ell}^c_p T^A u_r)\epsilon_{jk}D^\mu(\overline{q}^k_s T^A d_t)$
$Q^{(3)}_{\ell^2 u d D^2}$	$(\overline{q}^c_p\overleftrightarrow{D}^\mu u_r)\epsilon_{jk}(\overline{q}^k_s\overleftrightarrow{D}_\mu d_t)$
$Q^{(1)}_{\ell e q u D^2}$	$D_\mu(\overline{\ell}^c_p e_r)\epsilon_{jk}D^\mu(\overline{q}^k_s u_t)$
$Q^{(2)}_{\ell e q u D^2}$	$D_\mu(\overline{\ell}^c_p w^a_\mu)\epsilon_{jk}D^\nu(\overline{q}^k_{w\nu}e_t)$
$Q^{(3)}_{\ell e q u D^2}$	$(\overline{\ell}^c_p\overleftrightarrow{D}^\mu e_r)\epsilon_{jk}(\overline{q}^k_s\overleftrightarrow{D}_\mu u_t)$

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

SMEFT at $d = 8$: Murphy basis

$\mathbf{21 : (\bar{L}L)(\bar{L}L)D^2}$	
$Q^{(1)}_{\ell\ell D^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\ell_r)D_\nu(\overline{\ell}_s\gamma_\mu\ell_t)$
$Q^{(2)}_{\ell\ell D^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^\nu\ell_r)(\overline{\ell}_s\gamma_\mu\overleftrightarrow{D}_\nu\ell_t)$
$Q^{(1)}_{qqD^2}$	$D^\nu(\overline{q}_p\gamma^\mu q_r)D_\nu(\overline{q}_s\gamma_\mu q_t)$
$Q^{(2)}_{qqD^2}$	$(\overline{q}_p\gamma^\mu\overleftrightarrow{D}^\nu q_r)(\overline{q}_s\gamma_\mu\overleftrightarrow{D}_\nu q_t)$
$Q^{(3)}_{qqD^2}$	$D^\nu(\overline{q}_p\gamma^\mu\tau^I q_r)D_\nu(\overline{q}_s\gamma_\mu\tau^I q_t)$
$Q^{(4)}_{qqD^2}$	$(\overline{q}_p\gamma^\mu\overleftrightarrow{D}^{I\nu}q_r)(\overline{q}_s\gamma_\mu\overleftrightarrow{D}^I_\nu q_t)$
$Q^{(1)}_{\ell qD^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\ell_r)D_\nu(\overline{q}_s\gamma_\mu q_t)$
$Q^{(2)}_{\ell qD^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^\nu\ell_r)(\overline{q}_s\gamma_\mu\overleftrightarrow{D}_\nu q_t)$
$Q^{(3)}_{\ell qD^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\tau^I\ell_r)D_\nu(\overline{q}_s\gamma_\mu\tau^I q_t)$
$Q^{(4)}_{\ell qD^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^{I\nu}\ell_r)(\overline{q}_s\gamma_\mu\overleftrightarrow{D}^I_\nu q_t)$

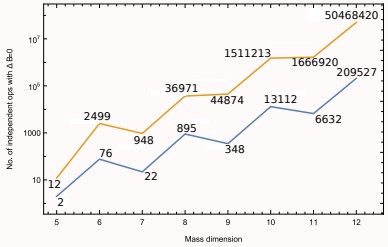
$\mathbf{21 : (\bar{R}R)(\bar{R}R)D^2}$	
Q_{eeD^2}	$D^\nu(\overline{e}_p\gamma^\mu e_r)D_\nu(\overline{e}_s\gamma_\mu e_t)$
$Q^{(1)}_{uuD^2}$	$D^\nu(\overline{u}_p\gamma^\mu u_r)D_\nu(\overline{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{uuD^2}$	$(\overline{u}_p\gamma^\mu\overleftrightarrow{D}^\nu u_r)(\overline{u}_s\gamma_\mu\overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{ddD^2}$	$D^\nu(\overline{d}_p\gamma^\mu d_r)D_\nu(\overline{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{ddD^2}$	$(\overline{d}_p\gamma^\mu\overleftrightarrow{D}^\nu d_r)(\overline{d}_s\gamma_\mu\overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{euD^2}$	$D^\nu(\overline{e}_p\gamma^\mu e_r)D_\nu(\overline{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{euD^2}$	$(\overline{e}_p\gamma^\mu\overleftrightarrow{D}^\nu e_r)(\overline{u}_s\gamma_\mu\overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{edD^2}$	$D^\nu(\overline{e}_p\gamma^\mu e_r)D_\nu(\overline{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{edD^2}$	$(\overline{e}_p\gamma^\mu\overleftrightarrow{D}^\nu e_r)(\overline{d}_s\gamma_\mu\overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{udD^2}$	$D^\nu(\overline{u}_p\gamma^\mu u_r)D_\nu(\overline{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{udD^2}$	$(\overline{u}_p\gamma^\mu\overleftrightarrow{D}^\nu u_r)(\overline{d}_s\gamma_\mu\overleftrightarrow{D}_\nu d_t)$
$Q^{(3)}_{udD^2}$	$D^\nu(\overline{u}_p\gamma^\mu T^A u_r)D_\nu(\overline{d}_s\gamma_\mu T^A d_t)$
$Q^{(4)}_{udD^2}$	$(\overline{u}_p\gamma^\mu T^A\overleftrightarrow{D}^\nu u_r)(\overline{d}_s\gamma_\mu T^A\overleftrightarrow{D}_\nu d_t)$

$\mathbf{21 : (\bar{L}L)(\bar{R}R)D^2}$	
$Q^{(1)}_{\ell eD^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\ell_r)D_\nu(\overline{e}_s\gamma_\mu e_t)$
$Q^{(2)}_{\ell eD^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^\nu\ell_r)(\overline{e}_s\gamma_\mu\overleftrightarrow{D}_\nu e_t)$
$Q^{(1)}_{\ell uD^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\ell_r)D_\nu(\overline{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{\ell uD^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^\nu\ell_r)(\overline{u}_s\gamma_\mu\overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{\ell dD^2}$	$D^\nu(\overline{\ell}_p\gamma^\mu\ell_r)D_\nu(\overline{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{\ell dD^2}$	$(\overline{\ell}_p\gamma^\mu\overleftrightarrow{D}^\nu\ell_r)(\overline{d}_s\gamma_\mu\overleftrightarrow{D}_\nu d_t)$
$Q^{(1)}_{qeD^2}$	$D^\nu(\overline{q}_p\gamma^\mu q_r)D_\nu(\overline{e}_s\gamma_\mu e_t)$
$Q^{(2)}_{qeD^2}$	$(\overline{q}_p\gamma^\mu\overleftrightarrow{D}^\nu q_r)(\overline{e}_s\gamma_\mu\overleftrightarrow{D}_\nu e_t)$
$Q^{(1)}_{quD^2}$	$D^\nu(\overline{q}_p\gamma^\mu q_r)D_\nu(\overline{u}_s\gamma_\mu u_t)$
$Q^{(2)}_{quD^2}$	$(\overline{q}_p\gamma^\mu\overleftrightarrow{D}^\nu q_r)(\overline{u}_s\gamma_\mu\overleftrightarrow{D}_\nu u_t)$
$Q^{(3)}_{quD^2}$	$D^\nu(\overline{q}_p\gamma^\mu T^A q_r)D_\nu(\overline{u}_s\gamma_\mu T^A u_t)$
$Q^{(4)}_{quD^2}$	$(\overline{q}_p\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)(\overline{u}_s\gamma_\mu T^A\overleftrightarrow{D}_\nu u_t)$
$Q^{(1)}_{qdD^2}$	$D^\nu(\overline{q}_p\gamma^\mu q_r)D_\nu(\overline{d}_s\gamma_\mu d_t)$
$Q^{(2)}_{qdD^2}$	$(\overline{q}_p\gamma^\mu\overleftrightarrow{D}^\nu q_r)(\overline{d}_s\gamma_\mu\overleftrightarrow{D}_\nu d_t)$
$Q^{(3)}_{qdD^2}$	$D^\nu(\overline{q}_p\gamma^\mu T^A q_r)D_\nu(\overline{d}_s\gamma_\mu T^A d_t)$
$Q^{(4)}_{qdD^2}$	$(\overline{q}_p\gamma^\mu T^A\overleftrightarrow{D}^\nu q_r)(\overline{d}_s\gamma_\mu T^A\overleftrightarrow{D}_\nu d_t)$

$\mathbf{21 : (\bar{L}R)(L\bar{R})D^2 + h.c.}$	
$Q^{(1)}_{\varphi udD^2}$	$D_\mu(\overline{q}_p^j u_r)\epsilon_{jk}D^\mu(\overline{q}_s^k d_t)$
$Q^{(2)}_{\varphi udD^2}$	$D_\mu(\overline{q}_p^j T^A u_r)\epsilon_{jk}D^\mu(\overline{q}_s^k T^A d_t)$
$Q^{(3)}_{\varphi udD^2}$	$(\overline{q}_p^j\overleftrightarrow{D}^\mu u_r)\epsilon_{jk}(\overline{q}_s^k\overleftrightarrow{D}_\mu d_t)$
$Q^{(1)}_{lequD^2}$	$D_\mu(\overline{l}_p^j e_r)\epsilon_{jk}D^\mu(\overline{q}_s^k u_t)$
$Q^{(2)}_{lequD^2}$	$D_\mu(\overline{l}_p^j\sigma^{\mu\nu}e_r)\epsilon_{jk}D^\sigma(\overline{q}^k_{s\nu}e_t)$
$Q^{(3)}_{lequD^2}$	$(\overline{l}_p^j\overleftrightarrow{D}^\mu e_r)\epsilon_{jk}(\overline{q}_s^k\overleftrightarrow{D}_\mu u_t)$

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

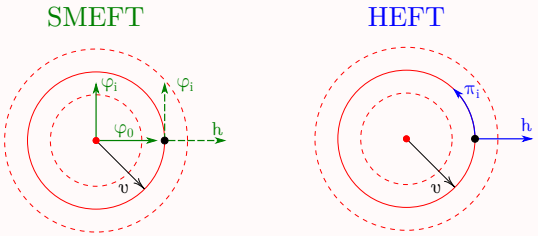
The Higgs Effective Field Theory – HEFT

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. . .

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

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



HEFT notation basics

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

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

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

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

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 ⊃ SMEFT ⊃ SM

- in general **more convergent** than SMEFT: takes fewer orders to reproduce well UV model
  → $\mathcal{F}(h)$ resums powers of $(H^\dagger H)$ ~ geoSMEFT: Helset,(Paraskevas,Martin),Trott 1803.08001,2001.01453
  → 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 $\mathscr{L}_{HEFT} = \mathscr{L}_0 + \mathscr{L}_1 + \mathscr{L}_2 + \dots$

  $\mathscr{L}_1$ = 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 $\mathscr{L}_1$

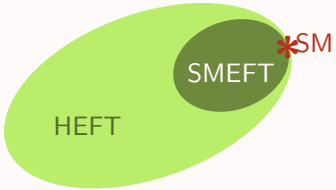
39 operators (vs **15** in dim-6 Warsaw basis, **89** in dim-8 Murphy basis) Sun,Xiao,Yu 2206.07722

$$
\begin{array}{lll}
\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)
\end{array}
$$

HEFT vs SMEFT

- how do they compare phenomenologically?
- are there any unambiguous signatures of HEFT = non-SMEFT BSM?
- can SMEFT be ruled out?
- can non-SMEFT BSM be ruled out?

  eg. unitarity arguments suggest these scenarios require
  $\Lambda \lesssim 4\pi v \sim 3$ TeV Cohen,Craig,Lu,Sutherland 2108.03240



- can HEFT still be useful for models that technically match onto SMEFT?
  - we know it works better than SMEFT for poorly convergent H series (composite H)
  - can it be a good-enough alternative to dim-8 for LHC?

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

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

two main classes of differences:

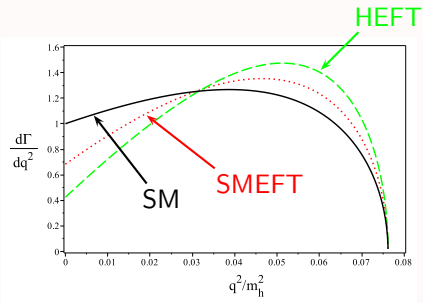
- interactions that are **correlated in SMEFT** and **decorrelated in HEFT**
- interactions that appear at **a lower order in HEFT** compared to SMEFT

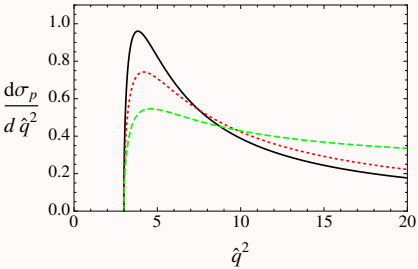
Example 1. $h \to V\bar{f}f$ / $\bar{f}f \to Vh$

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)





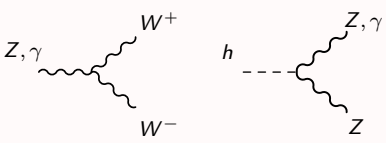
SMEFT $\mathscr{L}_6$ vs. HEFT $\mathscr{L}_1$

two main classes of differences:

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

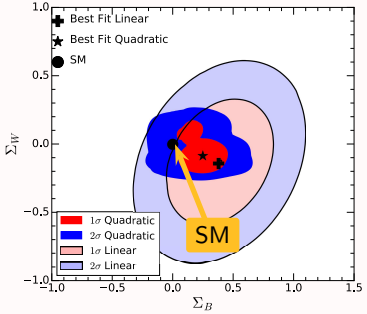
Example 2. VVV vs VVh interactions

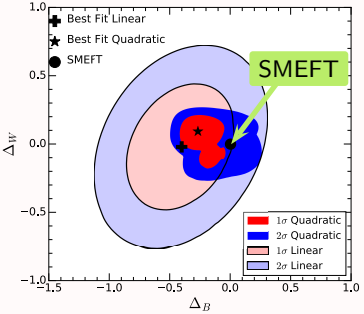
Éboli,Gonzalez-Garcia,Martines 2112.11468. also: IB et al 1311.1823,1604.06801



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

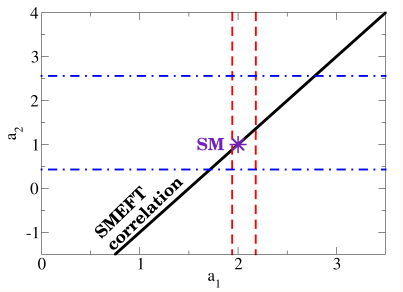
Example 3. $V_L V_L \to h^n$ at large s

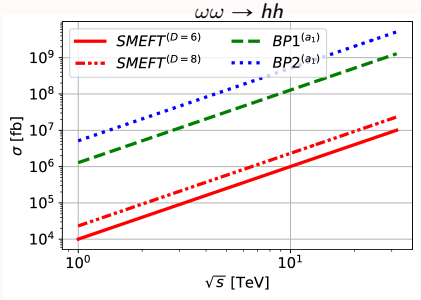
Gomez-Ambrosio et al 2204.01763, Delgado et al 2311.04280

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

vs.

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





Are order-by-order considerations enough?

👍 EFTs must be truncated for pheno

→ order-by-order comparisons tell us what we'd be working with in practice

→ direct consequence of the **different power-counting** implemented

👎 they do not answer more fundamental questions

→ 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?

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.

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

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

- accidental $SU(2)_L \times SU(2)_R \sim O(4)$ symmetry: $H^\dagger H = \frac{|\vec{\phi}|^2}{2}$
- 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.

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

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

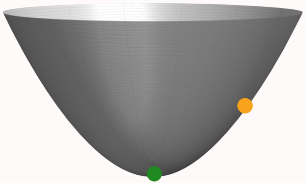
Cheung,Helset,Parra-Martinez 2111.03045,2202.06972
Helset,Jenkins,Manohar 2210.08000
Assi,Helset,Manohar,Pagès,Shen 2307.03187
Cohen,Lu,Sutherland 2312.06748

Scenarios requiring HEFT

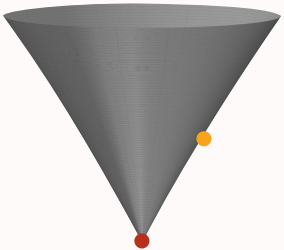
Cohen et al 2008.0597, 2108.03240, Banta et al 2110.02967. figs by D. Sutherland

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

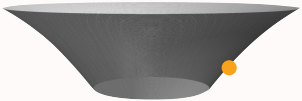


✔ SMEFT



✖ HEFT only

"loryons"



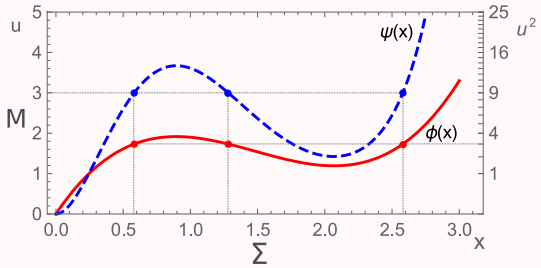
✖ HEFT only

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 $\rightarrow$ 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 $\phi \rightarrow$ **Lagrangian**

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

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

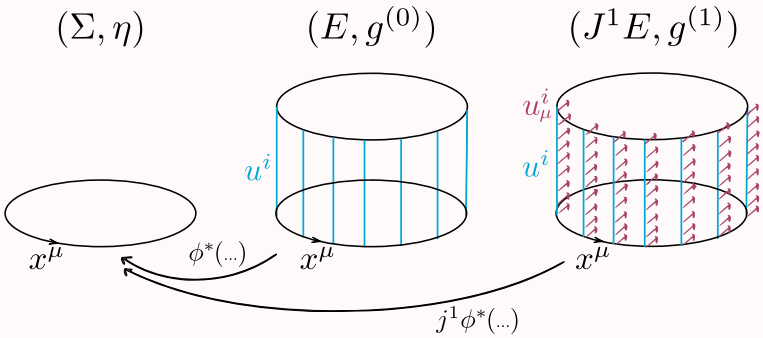
g_{ij} has the same interpretation as before. physics also requires

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

$\rightarrow$ geometric description of the scalar potential!

Jet bundles

Saunders 1989. see also Craig,Lee 2307.15742



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

J^rE = r-jet bundle = $\{j^r_x\phi | x \in \Sigma, \phi \in \Gamma_x(\pi)\}$ is a differentiable manifold. we use only J^1E

Scalar Lagrangian from 1-jet bundle geometry

J^{1}E 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**

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

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

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

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

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

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pulls back to

$$\mathscr{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi\big(C + 2G + J - 2E'\big) - \Lambda^4 V \qquad \text{blue} = \text{can be removed via EOM}$$

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

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 $y^I = (x^\mu, u^i, u^i_{\mu_1}, u^i_{\mu_1\mu_2}, \dots, u^i_{\mu_1\dots\mu_r})$

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

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

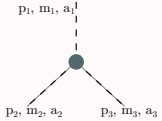
Connection to scattering amplitudes

Alminawi,IB,Davighi in progress

- our next goal is being able to write scattering amplitudes as a function of covariant objects
  → explicit independence under field redef.
- in usual geometric picture (fields = coordinates) this is considered a solved issue

  Helset et al 2111.03045,2202.06972,2210.08000, Nagai et al 1904.07618, Cohen et al 2108.03240...

  eg. off-shell 3-point function ($\bar{X}$ = X evaluated at vacuum, $A_{,b} = \partial_b A$)



$$= \bar{V}_{,a_1a_2a_3} - \left[(p_1^2 - m_1^2)\bar{g}_{a_1b}\bar{\Gamma}^{b}_{\ a_2a_3} + \text{perm}\right]$$

- at the 2-derivatives level, we should be able to reproduce this result in the bundle (= 0-jet) bundle geometry is much more complex! but hopefully also more powerful

$$\frac{1}{2}\left[\overline{\nabla_{a_3} R^{\mu}_{a_1\mu a_2}} - \left[(p_1^2 - m_1^2)\bar{\Gamma}_{a_1a_2a_3} + (p_1^2 - m_1^2)\bar{\Gamma}_{a_2a_1a_3} + (p_1^2 - m_1^2)\bar{\Gamma}_{a_3a_2a_1}\right]\right]$$

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

a new COST Action!

"COmprehensive Multiboson Experiment-Theory Action"

very broad scientific program

- **SMEFT/HEFT studies** of multi-boson processes (as many H/W/Z as wished), also with global perspective
- **precision calculations** and development of MC, PS etc
- **W, Z polarizations**: conventions, higher-order predictions, MC
- development of **ML-based tools**, together with ML experts outside academia: polarization taggers, jet taggers for VBF topologies, optimal observables...

€ for networking: will organize **workshops, schools, topical meetings**
+ funds for short/medium-term **visits** to other institutions within Europe

currently $\sim 1/3$ theorists + $2/3$ experimentalists + a few ML experts

activities just started! **EFT mtg** in June, **polarizations mtg** in September & more

sign up & **more info** at `www.cost.eu/actions/CA22130/`

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

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

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

gives

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

→ 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 $A, B, C \ldots$ 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} \\
&\quad + \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_\sigma \cdot u^\sigma}{\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} \\
&\quad + \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_j^\nu \, 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_i u_j}{\Lambda^2} C_1 + \delta_{ij} \frac{u_\rho \cdot u^\rho}{\Lambda^4} D_0 + \frac{u_{i\rho} u_j^\rho}{\Lambda^4} D_1 + \left[\delta_{ij} \frac{(u \cdot u_\rho)^2}{\Lambda^6} + \frac{u_i u_j \, u_\rho \cdot u^\rho}{\Lambda^6} \right] \frac{D_2}{2} + \frac{(u_i u_{j\rho} + u_j u_{i\rho}) \, u \cdot u^\rho}{\Lambda^6} \frac{D_3}{2} + \frac{u_i u_j (u \cdot u_\rho)^2}{\Lambda^8} D_4 \\
\Lambda g^\mu_{ij} &= \frac{u_i^\mu u_j}{\Lambda^3} B_0 + \frac{u_i u_j^\mu}{\Lambda^3} B_1 + \delta_{ij} \frac{u \cdot u^\mu}{\Lambda^3} B_2 + \frac{u_i u_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_i u_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 $\rightarrow$ 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
$L^{\psi_L}_{pr,A}(\phi)(D^\mu\phi)^J(\bar{\psi}_{p,L}\gamma_\mu\sigma_A\psi_{r,L})$	$2\,N_f^2$	$4\,N_f^2$	$4\,N_f^2$	$4\,N_f^2$	$4\,N_f^2$

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

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

$(B_{\mu\nu}B^{\mu\nu})(H^\dagger H)^n$

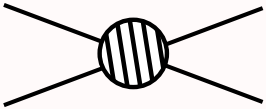
$(W^i_{\mu\nu}W^{i\mu\nu})(H^\dagger H)^n$

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

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

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