Leading Directions and RG Effects in the SMEFT

In collaboration with: Admir Greljo and Aleks Smolkovič

Based on arXiv: [2305.08898] and [2312.09179]

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Ajdin Palavrić

Introduction SMEFT, Operators and Flavor Symmetries

Introduction: SMEFT



- In the EFT program, Standard Model effective field theory (SMEFT) is of particular relevance
- Connection of BSM physics and the low energy EFTs
- Construction of the SMEFT:
- SM fields + symmetries (gauge and Poincaré)
 - Existence of the scale separation
 - Higher-dimensional operators

$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{\text{SM}} + \frac{1}{\Lambda} \mathscr{L}_5 + \frac{1}{\Lambda^2} \mathscr{L}_6 + \mathscr{O}(\Lambda^{-3})$$





Introduction: SMEFT operators and bases



- Higher-dimensional operators are collected in the nonredundant operator bases
 - Dimension 6 Grzadkowski, Iskrzynski, Misiak, Rosiek [1008.4884]
 - **Dimension** 7 Liao, Ma [1612.04527], Lehman [1410.4193]
 - **Dimension 8** Murphy [2005.00059]
 - Hilbert series Henning, Lu, Melia, Murayama [1507.07240]
 - Marinissen, Rahn, Waalewijn [2004.09521]
 - Automation tools
 - Sym2Int Fonseca [1703.05221]
 - **AutoEFT** Harlander, Schaaf [2309.15783]





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Introduction: dimension-6 operators

- Large number of independent parameters already at dimension 6
 - Single generation: 59
 - Three generations: 2499 lacksquare

	X^3		$arphi^6 ext{ and } arphi^4 D^2$	$\psi^2 arphi$	
Q_G	$f^{ABC}G^{A u}_{\mu}G^{B ho}_{ u}G^{C\mu}_{ ho}$	Q_{arphi}	$(arphi^\daggerarphi)^3$	Q_{earphi}	$(arphi^\dagger arphi)$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}^{A u}_{\mu}G^{B ho}_{ u}G^{C\mu}_{ ho}$	$Q_{arphi \Box}$	$(arphi^\daggerarphi) \Box (arphi^\daggerarphi)$	Q_{uarphi}	$(arphi^\dagger arphi)$
Q_W	$arepsilon^{IJK}W^{I u}_{\mu}W^{J ho}_{ u}W^{K\mu}_{ ho}$	$Q_{arphi D}$	$\left(arphi^{\dagger} D^{\mu} arphi ight)^{\star} \left(arphi^{\dagger} D_{\mu} arphi ight)$	Q_{darphi}	$(arphi^\dagger arphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I u}_{\mu}W^{J ho}_{ u}W^{K\mu}_{ ho}$				
	$X^2 arphi^2$		$\psi^2 X arphi$		$\psi^2 arphi^2$
$Q_{arphi G}$	$arphi^\dagger arphi G^A_{\mu u} G^{A\mu u}$	Q_{eW}	$(ar{l}_p\sigma^{\mu u}e_r) au^Iarphi W^I_{\mu u}$	$Q^{(1)}_{arphi l}$	$(arphi^\dagger i \overleftrightarrow{D})$
$Q_{arphi \widetilde{G}}$	$arphi^\dagger arphi \widetilde{G}^A_{\mu u} G^{A\mu u}$	Q_{eB}	$(ar{l}_p\sigma^{\mu u}e_r)arphi B_{\mu u}$	$Q^{(3)}_{arphi l}$	$(arphi^\dagger i \overleftrightarrow{D}^I_\mu$
$Q_{arphi W}$	$arphi^\dagger arphi W^I_{\mu u} W^{I\mu u}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu u} T^A u_r) \widetilde{\varphi} G^A_{\mu u}$	$Q_{arphi e}$	$(arphi^\dagger i \overleftrightarrow{D}_{\mu}$
$Q_{arphi \widetilde{W}}$	$arphi^\dagger arphi \widetilde{W}^I_{\mu u} W^{I\mu u}$	Q_{uW}	$(ar{q}_p \sigma^{\mu u} u_r) au^I \widetilde{arphi} W^I_{\mu u}$	$Q^{(1)}_{arphi q}$	$(arphi^\dagger i \overleftrightarrow{D}_{\mu})$
$Q_{arphi B}$	$arphi^\dagger arphi B_{\mu u} B^{\mu u}$	Q_{uB}	$(ar q_p \sigma^{\mu u} u_r) \widetilde arphi B_{\mu u}$	$Q^{(3)}_{arphi q}$	$(arphi^\dagger i \overleftrightarrow{D}^I_\mu$
$Q_{arphi \widetilde{B}}$	$arphi^\dagger arphi \widetilde{B}_{\mu u} B^{\mu u}$	Q_{dG}	$(ar{q}_p \sigma^{\mu u} T^A d_r) arphi G^A_{\mu u}$	$Q_{arphi u}$	$(arphi^\dagger i \overleftrightarrow{D}_{\!\mu}$
$Q_{arphi WB}$	$arphi^\dagger au^I arphi W^I_{\mu u} B^{\mu u}$	Q_{dW}	$(ar{q}_p \sigma^{\mu u} d_r) au^I arphi W^I_{\mu u}$	$Q_{arphi d}$	$(arphi^\dagger i \overleftrightarrow{D}_{\!\mu}$
$Q_{arphi \widetilde{W}B}$	$arphi^\dagger au^I arphi \widetilde{W}^I_{\mu u} B^{\mu u}$	Q_{dB}	$(ar q_p \sigma^{\mu u} d_r) arphi B_{\mu u}$	$Q_{arphi u d}$	$i(\widetilde{arphi}^\dagger D_\mu$

	$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)$
Q_{ll}	$(ar{l}_p\gamma_\mu l_r)(ar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(ar{e}_p\gamma_\mu e_r)(ar{e}_s\gamma^\mu e_t)$	Q_{le}	$(ar{l}_p\gamma_\mu$
$Q_{qq}^{(1)}$	$(ar q_p \gamma_\mu q_r) (ar q_s \gamma^\mu q_t)$	Q_{uu}	$(ar{u}_p\gamma_\mu u_r)(ar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(ar{l}_p \gamma_\mu$
$Q_{qq}^{(3)}$	$(ar q_p \gamma_\mu au^I q_r) (ar q_s \gamma^\mu au^I q_t)$	Q_{dd}	$(ar{d}_p\gamma_\mu d_r)(ar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(ar{l}_p\gamma_\mu$
$Q_{lq}^{(1)}$	$(ar{l}_p\gamma_\mu l_r)(ar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(ar{e}_p\gamma_\mu e_r)(ar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(ar{q}_p\gamma_\mu$
$Q_{lq}^{(3)}$	$(ar{l}_p\gamma_\mu au^I l_r)(ar{q}_s\gamma^\mu au^I q_t)$	Q_{ed}	$(ar{e}_p\gamma_\mu e_r)(ar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{\left(1 ight) }$	$(ar{q}_p \gamma_\mu$
		$Q_{ud}^{\left(1 ight) }$	$(ar{u}_p\gamma_\mu u_r)(ar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$\left(ar{q}_p \gamma_\mu T^A ight)$
		$Q_{ud}^{(8)}$	$(ar{u}_p \gamma_\mu T^A u_r) (ar{d}_s \gamma^\mu T^A d_t)$	$Q_{qd}^{\left(1 ight)}$	$(ar{q}_p\gamma_\mu$
				$Q_{qd}^{(8)}$	$(ar{q}_p \gamma_\mu T^A)$
$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-viol	lating	
Q_{ledq}	$(ar{l}_p^j e_r) (ar{d}_s q_t^j)$	Q_{duq}	$arepsilon^{lphaeta\gamma}arepsilon_{jk}\left[(d_p^lpha) ight.$	$^{T}Cu_{r}^{\beta}]$	$\left[(q_s^{\gamma j})^T C ight.$
$\left \begin{array}{c} Q_{quqd}^{(1)} \end{array} ight $	$(ar{q}_p^j u_r) arepsilon_{jk} (ar{q}_s^k d_t)$	Q_{qqu}	$arepsilon^{lphaeta\gamma}arepsilon_{jk}\left[(q_p^{lpha j}) ight]$	$^{T}Cq_{r}^{\beta k}$	$\left[(u_s^{\gamma})^T C \right]$
$Q_{quqd}^{(8)}$	$(ar{q}_p^j T^A u_r) arepsilon_{jk} (ar{q}_s^k T^A d_t)$	Q_{qqq}	$arepsilon^{lphaeta\gamma}arepsilon_{jn}arepsilon_{km}\left[(q_p^lpha) ight]$	$^{j})^{T}Cq_{r}^{eta}$	$\left[\left(q_{s}^{\gamma m} ight) ight]$
$Q_{lequ}^{(1)}$	$(ar{l}_p^j e_r) arepsilon_{jk} (ar{q}_s^k u_t)$	Q_{duu}	$arepsilon^{lphaeta\gamma}\left[(d_p^lpha)^T ight]$	$\left[Cu_{r}^{\beta} ight] \left[ight]$	$(u_s^{\gamma})^T Ce_t$
$Q_{lequ}^{(3)}$	$(ar{l}_p^j\sigma_{\mu u}e_r)arepsilon_{jk}(ar{q}_s^k\sigma^{\mu u}u_t)$				









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- Large number of independent parameters already at dimension 6
 - Single generation: 59 •
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- This suggests that the proliferation of parameters originates from the flavor structure

	X^3		$arphi^6$ and $arphi^4 D^2$		$\psi^2 arphi$
Q_G	$f^{ABC}G^{A u}_{\mu}G^{B ho}_{ u}G^{C\mu}_{ ho}$	Q_arphi	$(arphi^\dagger arphi)^3$	Q_{earphi}	$(arphi^{\dagger} arphi)$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}^{A u}_{\mu}G^{B ho}_{ u}G^{C\mu}_{ ho}$	$Q_{arphi \Box}$	$(arphi^\daggerarphi) \Box (arphi^\daggerarphi)$	Q_{uarphi}	$(arphi^{\dagger}arphi)$
Q_W	$arepsilon^{IJK}W^{I u}_{\mu}W^{J ho}_{ u}W^{K\mu}_{ ho}$	$Q_{arphi D}$	$\left(arphi^{\dagger}D^{\mu}arphi ight)^{\star} \left(arphi^{\dagger}D_{\mu}arphi ight)$	Q_{darphi}	$(arphi^\dagger arphi)$
$Q_{\widetilde{W}}$	$arepsilon^{IJK}\widetilde{W}^{I u}_{\mu}W^{J ho}_{ u}W^{K\mu}_{ ho}$				
$X^2 \varphi^2$			$\psi^2 X arphi$		$\psi^2 arphi^2$
$Q_{arphi G}$	$arphi^\dagger arphi G^A_{\mu u} G^{A\mu u}$	Q_{eW}	$(ar{l}_p \sigma^{\mu u} e_r) au^I arphi W^I_{\mu u}$	$Q^{(1)}_{arphi l}$	$(\varphi^{\dagger}i\overleftrightarrow{D}$
$Q_{arphi \widetilde{G}}$	$arphi^\dagger arphi \widetilde{G}^A_{\mu u} G^{A\mu u}$	Q_{eB}	$(ar{l}_p \sigma^{\mu u} e_r) arphi B_{\mu u}$	$Q^{(3)}_{arphi l}$	$\left \left(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I} ight. ight.$
$Q_{arphi W}$	$arphi^\dagger arphi W^I_{\mu u} W^{I\mu u}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu u} T^A u_r) \widetilde{\varphi} G^A_{\mu u}$	$Q_{arphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D})$
$\left\ ~~ Q_{arphi \widetilde{W}} ight.$	$arphi^\dagger arphi \widetilde{W}^I_{\mu u} W^{I\mu u}$	Q_{uW}	$(ar{q}_p \sigma^{\mu u} u_r) au^I \widetilde{arphi} W^I_{\mu u}$	$Q^{(1)}_{arphi q}$	$(\varphi^{\dagger}i\overleftrightarrow{D})$
$Q_{\varphi B}$	$arphi^\dagger arphi B_{\mu u} B^{\mu u}$	Q_{uB}	$(ar q_p \sigma^{\mu u} u_r) \widetilde arphi B_{\mu u}$	$Q^{(3)}_{arphi q}$	$\left \ (\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}) \right $
$Q_{arphi \widetilde{B}}$	$arphi^\dagger arphi \widetilde{B}_{\mu u} B^{\mu u}$	Q_{dG}	$(ar{q}_p \sigma^{\mu u} T^A d_r) arphi G^A_{\mu u}$	$Q_{arphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu})$
$Q_{\varphi WB}$	$arphi^\dagger au^I arphi W^I_{\mu u} B^{\mu u}$	Q_{dW}	$(ar{q}_p \sigma^{\mu u} d_r) au^I arphi W^I_{\mu u}$	$Q_{arphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D})$
$Q_{arphi \widetilde{W}B}$	$arphi^\dagger au^I arphi \widetilde{W}^I_{\mu u} B^{\mu u}$	Q_{dB}	$(ar q_p \sigma^{\mu u} d_r) arphi B_{\mu u}$	$Q_{arphi u d}$	$i(\widetilde{arphi}^{\dagger}D)$

		$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)($	
	Q_{ll}	$(ar{l}_p \gamma_\mu l_r) (ar{l}_s \gamma^\mu l_t)$	Q_{ee}	$(ar{e}_p\gamma_\mu e_r)(ar{e}_s\gamma^\mu e_t)$	Q_{le}	$(ar{l}_p\gamma_\mu$	
	$Q_{qq}^{\left(1 ight)}$	$(ar q_p \gamma_\mu q_r) (ar q_s \gamma^\mu q_t)$	Q_{uu}	$(ar{u}_p\gamma_\mu u_r)(ar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(ar{l}_p\gamma_\mu$	
	$Q_{qq}^{\left(3 ight) }$	$(ar q_p \gamma_\mu au^I q_r) (ar q_s \gamma^\mu au^I q_t)$	Q_{dd}	$(ar{d}_p\gamma_\mu d_r)(ar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(ar{l}_p \gamma_\mu$	
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			$Q_{ud}^{(1)}$	$(ar{u}_p\gamma_\mu u_r)(ar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$\left \left(\bar{q}_p \gamma_\mu T^A \right) \right $	
			$Q_{ud}^{(8)}$	$(ar{u}_p\gamma_\mu T^A u_r)(ar{d}_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(ar{q}_p\gamma_\mu$	
					$Q_{qd}^{(8)}$	$\left \left(\bar{q}_p \gamma_\mu T^A \right. \right. \right.$	
ſ	$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	<i>B</i> -violating				
	Q_{ledq}	$(ar{l}_p^j e_r) (ar{d}_s q_t^j)$	Q_{duq}	$arepsilon^{lphaeta\gamma}arepsilon_{jk}\left[(d_p^lpha) ight.$	$^{T}Cu_{r}^{\beta}]$	$\left[(q_s^{\gamma j})^T C ight]$	
	$Q_{quqd}^{\left(1 ight)}$	$(ar{q}_p^j u_r) arepsilon_{jk} (ar{q}_s^k d_t)$	Q_{qqu}	$arepsilon^{lphaeta\gamma}arepsilon_{jk}\left[(q_p^{lpha j}) ight]$	$^{T}Cq_{r}^{\beta k}$	$\left[(u_s^{\gamma})^T C \right]$	
	$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	Q_{qqq}	$arepsilon^{lphaeta\gamma}arepsilon_{jn}arepsilon_{km}\left[(q_p^lpha) ight]$	$^{j})^{T}Cq_{r}^{\beta}$	$\left[\left(q_{s}^{\gamma m} ight)^{2} ight]$	
	$Q_{lequ}^{\left(1 ight)}$	$(ar{l}_p^j e_r) arepsilon_{jk} (ar{q}_s^k u_t)$	Q_{duu}	$arepsilon^{lphaeta\gamma}\left[(d_p^lpha)^T ight.$	$Cu_r^{\beta}] [$	$(u_s^{\gamma})^T Ce_t$	
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- In the Standard Model

$$U(3)^{5} = U(3)_{q} \times U(3)_{\ell} \times U(3)_{u} \times U(3)_{d} \times U(3)_{d}$$

		X^3
Conoratora	Q_G	$\int f^{ABC} G^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C}_{\rho}$
o operators	$Q_{\widetilde{G}}$	$\int f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C}_{\rho}$
	Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{J\rho}_{\rho}$
	$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{I}_{\rho}$
alroady at		$X^2 arphi^2$
aneady at	$Q_{arphi G}$	$\varphi^{\dagger}\varphiG^{A}_{\mu\nu}G^{A\mu\nu}$
	$Q_{arphi \widetilde{G}}$	$arphi^\dagger arphi \widetilde{G}^A_{\mu u} G^{A\mu u}$
	$Q_{arphi W}$	$arphi^{\dagger} arphi W^{I}_{\mu u} W^{I\mu u}$
	$Q_{arphi \widetilde{W}}$	$arphi^{\dagger} arphi \widetilde{W}^{I}_{\mu u} W^{I\mu u}$
	$Q_{arphi B}$	$arphi^\dagger arphi B_{\mu u} B^{\mu u}$
	$Q_{arphi \widetilde{B}}$	$arphi^\dagger arphi \widetilde{B}_{\mu u} B^{\mu u}$
	$Q_{arphi WB}$	$arphi^\dagger au^I arphi W^I_{\mu u} B^{\mu u}$
	$Q_{arphi \widetilde{W}B}$	$arphi^\dagger au^I arphi \widetilde{W}^I_{\mu u} B^{\mu u}$
meters		
		$(\bar{L}L)(\bar{L}L)$
		$(ar{l}_p\gamma_\mu l_r)(ar{l}_s\gamma^\mu l_t)$
	$Q_{qq}^{(1)}$	$(ar{q}_p\gamma_\mu q_r)(ar{q}_s\gamma^\mu q_t)$
	$Q_{qq}^{(3)}$	$\left \begin{array}{c} (\bar{q}_p \gamma_\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_r) \right $
	$\left \begin{array}{c}Q_{lq}^{(1)}\\Q^{(3)}\end{array}\right $	$(l_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$
$J(3)_e$		$(l_p \gamma_\mu \tau^* l_r)(q_s \gamma^\mu \tau^* q_i)$
	$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$
, the	Q_{ledq}	$(ar{l}_p^j e_r) (ar{d}_s q_t^j)$
$e_e \varphi e$	$Q_{quqd}^{(1)}$	$(ar{q}_p^j u_r) arepsilon_{jk} (ar{q}_s^k d_t)$
	$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A a_r)$
	$\left \begin{array}{c} Q_{lequ}^{(1)} \\ Q_{lequ}^{(2)} \end{array} \right $	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$
	$Q_{lequ}^{(3)}$	$\left (l_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_s) \right $

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$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}^{A u}_{\mu}G^{B ho}_{ u}G^{C\mu}_{ ho}$	$Q_{arphi \Box}$	$(arphi^\daggerarphi) \Box (arphi^\daggerarphi)$	Q_{uarphi}	$(arphi^{\dagger}arphi$
Q_W	$\varepsilon^{IJK}W^{I u}_{\mu}W^{J ho}_{ u}W^{K\mu}_{ ho}$	$Q_{arphi D}$	$\left(arphi^{\dagger} D^{\mu} arphi ight)^{\star} \left(arphi^{\dagger} D_{\mu} arphi ight)$	Q_{darphi}	$(arphi^{\dagger}arphi$
$Q_{\widetilde{W}}$	$arepsilon^{IJK}\widetilde{W}^{I u}_{\mu}W^{J ho}_{ u}W^{K\mu}_{ ho}$				
$X^2 \varphi^2$		$\psi^2 X arphi$			$\psi^2 arphi^2$
$Q_{arphi G}$	$arphi^\dagger arphi G^A_{\mu u} G^{A\mu u}$	Q_{eW}	$(ar{l}_p \sigma^{\mu u} e_r) au^I arphi W^I_{\mu u}$	$Q^{(1)}_{arphi l}$	$(arphi^\dagger i \overleftrightarrow{D}_{\mu}$
$Q_{arphi \widetilde{G}}$	$arphi^\dagger arphi \widetilde{G}^A_{\mu u} G^{A\mu u}$	Q_{eB}	$(ar{l}_p \sigma^{\mu u} e_r) arphi B_{\mu u}$	$Q^{(3)}_{arphi l}$	$(arphi^\dagger i \overleftrightarrow{D}^I_\mu)$
$Q_{arphi W}$	$arphi^\dagger arphi W^I_{\mu u} W^{I\mu u}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu u} T^A u_r) \widetilde{\varphi} G^A_{\mu u}$	$Q_{arphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}$
$Q_{arphi \widetilde{W}}$	$arphi^\dagger arphi \widetilde{W}^I_{\mu u} W^{I\mu u}$	Q_{uW}	$(ar{q}_p \sigma^{\mu u} u_r) au^I \widetilde{arphi} W^I_{\mu u}$	$Q^{(1)}_{arphi q}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}$
$Q_{arphi B}$	$arphi^\dagger arphi B_{\mu u} B^{\mu u}$	Q_{uB}	$(ar q_p \sigma^{\mu u} u_r) \widetilde arphi B_{\mu u}$	$Q^{(3)}_{arphi q}$	$\left \left(arphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}arphi ight) ight.$
$Q_{arphi \widetilde{B}}$	$arphi^\dagger arphi \widetilde{B}_{\mu u} B^{\mu u}$	Q_{dG}	$(ar{q}_p \sigma^{\mu u} T^A d_r) arphi G^A_{\mu u}$	$Q_{arphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}$
$Q_{arphi WB}$	$arphi^\dagger au^I arphi W^I_{\mu u} B^{\mu u}$	Q_{dW}	$(ar{q}_p \sigma^{\mu u} d_r) au^I arphi W^I_{\mu u}$	$Q_{arphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}$
$Q_{arphi \widetilde{W}B}$	$arphi^\dagger au^I arphi \widetilde{W}^I_{\mu u} B^{\mu u}$	Q_{dB}	$(ar q_p \sigma^{\mu u} d_r) arphi B_{\mu u}$	$Q_{arphi u d}$	$i(\widetilde{arphi}^{\dagger}D_{\mu}$

	$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$	$(\bar{L}L)(.$			
Q_{ll}	$(ar{l}_p\gamma_\mu l_r)(ar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(ar{e}_p\gamma_\mu e_r)(ar{e}_s\gamma^\mu e_t)$	Q_{le}	$(ar{l}_p\gamma_\mu b$		
$Q_{qq}^{(1)}$	$(ar q_p \gamma_\mu q_r) (ar q_s \gamma^\mu q_t)$	Q_{uu}	$(ar{u}_p \gamma_\mu u_r) (ar{u}_s \gamma^\mu u_t)$	Q_{lu}	$(ar{l}_p\gamma_\mu l$		
$Q_{qq}^{(3)}$	$(ar{q}_p\gamma_\mu au^I q_r)(ar{q}_s\gamma^\mu au^I q_t)$	Q_{dd}	$(ar{d}_p\gamma_\mu d_r)(ar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p \gamma_\mu l$		
$Q_{lq}^{(1)}$	$(ar{l}_p\gamma_\mu l_r)(ar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(ar{e}_p \gamma_\mu e_r) (ar{u}_s \gamma^\mu u_t)$	Q_{qe}	$(ar{q}_p\gamma_\mu q$		
$Q_{lq}^{(3)}$	$(ar{l}_p\gamma_\mu au^I l_r)(ar{q}_s\gamma^\mu au^I q_t)$	Q_{ed}	$(ar{e}_p\gamma_\mu e_r)(ar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(ar{q}_p\gamma_\mu q$		
		$Q_{ud}^{(1)}$	$(ar{u}_p\gamma_\mu u_r)(ar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$\left \left(ar{q}_p \gamma_\mu T^A q \right) \right $		
		$Q_{ud}^{(8)}$	$(ar{u}_p\gamma_\mu T^A u_r)(ar{d}_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(ar{q}_p\gamma_\mu q$		
				$Q_{qd}^{(8)}$	$\left \left(\bar{q}_p \gamma_\mu T^A q \right) \right $		
$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	<i>B</i> -violating					
Q_{ledq}	$(ar{l}_p^j e_r) (ar{d}_s q_t^j)$	Q_{duq}	$arepsilon^{lphaeta\gamma}arepsilon_{jk}\left[(d_p^lpha) ight.$	$^{T}Cu_{r}^{\beta}]$	$\left[(q_s^{\gamma j})^T C l ight.$		
$ig Q^{(1)}_{quqd}$	$(ar{q}_p^j u_r) arepsilon_{jk} (ar{q}_s^k d_t)$	Q_{qqu}	$arepsilon^{lphaeta\gamma}arepsilon_{jk}\left[(q_p^{lpha j}) ight]$	$^{T}Cq_{r}^{\beta k}$	$\left[(u_s^\gamma)^T C \right]$		
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	Q_{qqq}	$arepsilon^{lphaeta\gamma}arepsilon_{jn}arepsilon_{km}\left[(q_p^{lpha}) ight]$	$^{j})^{T}Cq_{r}^{eta}$	$\left[(q_s^{\gamma m})^T ight]$		
$Q_{lequ}^{(1)}$	$(ar{l}_p^j e_r) arepsilon_{jk} (ar{q}_s^k u_t)$	Q_{duu}	$arepsilon^{lphaeta\gamma}\left[(d_p^lpha)^T ight.$	$\left[Cu_{r}^{\beta} \right] \left[\right]$	$\left[(u_s^\gamma)^T C e_t ight]$		
$Q_{lequ}^{(3)}$	$(ar{l}_p^j\sigma_{\mu u}e_r)arepsilon_{jk}(ar{q}_s^k\sigma^{\mu u}u_t)$						









Introduction: dimension-6 operators

In the Standard Model

$$U(3)^{5} = U(3)_{q} \times U(3)_{\ell} \times U(3)_{u} \times U(3)_{d} \times U$$
$$-\mathscr{L}_{Y} = \bar{q}V^{\dagger}\hat{Y}_{u}\tilde{\phi}u + \bar{q}\hat{Y}_{d}\phi d + \bar{\ell}\hat{Y}_{u}$$
$$U(1)_{B} \times U(1)_{e} \times U(1)_{\mu} \times U(1)_{\tau}$$

- However, observed mass hierarchy and the CKM \bullet alignment point to approximate accidental symmetries
- This is the starting point of our analysis \bullet

 $(3)_{e}$

фe

X^3		$arphi^6 \;\; { m and} \;\; arphi^4 D^2$		$\psi^2 arphi$	
Q_G	$f^{ABC}G^{A u}_{\mu}G^{B ho}_{ u}G^{C\mu}_{ ho}$	Q_arphi	$(arphi^\dagger arphi)^3$	Q_{earphi}	$(arphi^{\dagger} arphi)$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}^{A u}_{\mu}G^{B ho}_{ u}G^{C\mu}_{ ho}$	$Q_{arphi \Box}$	$(arphi^\daggerarphi) \Box (arphi^\daggerarphi)$	Q_{uarphi}	$(arphi^\daggerarphi)$
Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{arphi D}$	$\left(arphi^\dagger D^\mu arphi ight)^\star \left(arphi^\dagger D_\mu arphi ight)$	Q_{darphi}	$(arphi^\dagger arphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I u}_{\mu}W^{J ho}_{ u}W^{K\mu}_{ ho}$				
$X^2 \varphi^2$			$\psi^2 X arphi$		$\psi^2 arphi^2$
$Q_{arphi G}$	$arphi^\dagger arphi G^A_{\mu u} G^{A\mu u}$	Q_{eW}	$(ar{l}_p \sigma^{\mu u} e_r) au^I arphi W^I_{\mu u}$	$Q^{(1)}_{arphi l}$	$(\varphi^{\dagger}i\overleftrightarrow{D}$
$Q_{arphi \widetilde{G}}$	$arphi^\dagger arphi \widetilde{G}^A_{\mu u} G^{A\mu u}$	Q_{eB}	$(ar{l}_p \sigma^{\mu u} e_r) arphi B_{\mu u}$	$Q^{(3)}_{arphi l}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I})$
$Q_{arphi W}$	$arphi^\dagger arphi W^I_{\mu u} W^{I\mu u}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu u} T^A u_r) \widetilde{\varphi} G^A_{\mu u}$	$Q_{arphi e}$	$(\varphi^{\dagger}i\overleftrightarrow{D})$
$\left\ ~~ Q_{arphi \widetilde{W}} ight.$	$arphi^\dagger arphi \widetilde{W}^I_{\mu u} W^{I\mu u}$	Q_{uW}	$(ar{q}_p \sigma^{\mu u} u_r) au^I \widetilde{arphi} W^I_{\mu u}$	$Q^{(1)}_{arphi q}$	$(arphi^\dagger i \overleftrightarrow{D})$
$Q_{arphi B}$	$arphi^\dagger arphi B_{\mu u} B^{\mu u}$	Q_{uB}	$(ar q_p \sigma^{\mu u} u_r) \widetilde arphi B_{\mu u}$	$Q^{(3)}_{arphi q}$	$\left \ (\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}) \right $
$Q_{arphi \widetilde{B}}$	$arphi^\dagger arphi \widetilde{B}_{\mu u} B^{\mu u}$	Q_{dG}	$(ar{q}_p\sigma^{\mu u}T^Ad_r)arphiG^A_{\mu u}$	$Q_{arphi u}$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu})$
$Q_{arphi WB}$	$arphi^\dagger au^I arphi W^I_{\mu u} B^{\mu u}$	Q_{dW}	$(ar{q}_p \sigma^{\mu u} d_r) au^I arphi W^I_{\mu u}$	$Q_{arphi d}$	$(\varphi^{\dagger}i\overleftrightarrow{D})$
$Q_{arphi \widetilde{W}B}$	$arphi^\dagger au^I arphi \widetilde{W}^I_{\mu u} B^{\mu u}$	Q_{dB}	$(ar q_p \sigma^{\mu u} d_r) arphi B_{\mu u}$	$Q_{arphi u d}$	$i(\widetilde{arphi}^{\dagger}D_{\mu})$

$\left[\right]$		$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$	$(\bar{L}L)$		
	Q_{ll}	$(ar{l}_p \gamma_\mu l_r) (ar{l}_s \gamma^\mu l_t)$	Q_{ee}	$(ar{e}_p\gamma_\mu e_r)(ar{e}_s\gamma^\mu e_t)$	Q_{le}	$(ar{l}_p\gamma_\mu$	
	$Q_{qq}^{\left(1 ight)}$	$(ar q_p \gamma_\mu q_r) (ar q_s \gamma^\mu q_t)$	Q_{uu}	$(ar{u}_p\gamma_\mu u_r)(ar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(ar{l}_p \gamma_\mu$	
	$Q_{qq}^{\left(3 ight) }$	$(ar q_p \gamma_\mu au^I q_r) (ar q_s \gamma^\mu au^I q_t)$	Q_{dd}	$(ar{d}_p\gamma_\mu d_r)(ar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(ar{l}_p\gamma_\mu$	
	$Q_{lq}^{\left(1 ight) }$	$(ar{l}_p\gamma_\mu l_r)(ar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(ar{e}_p\gamma_\mu e_r)(ar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(ar{q}_p\gamma_\mu$	
	$Q_{lq}^{\left(3 ight) }$	$(ar{l}_p\gamma_\mu au^I l_r)(ar{q}_s\gamma^\mu au^I q_t)$	Q_{ed}	$(ar{e}_p\gamma_\mu e_r)(ar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(ar{q}_p \gamma_\mu$	
			$Q_{ud}^{\left(1 ight) }$	$(ar{u}_p\gamma_\mu u_r)(ar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$\left(\bar{q}_p \gamma_\mu T^A \right)$	
			$Q_{ud}^{(8)}$	$(ar{u}_p\gamma_\mu T^A u_r)(ar{d}_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(ar{q}_p \gamma_\mu$	
					$Q_{qd}^{(8)}$	$(ar{q}_p \gamma_\mu T^A)$	
	$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	<i>B</i> -violating				
	Q_{ledq}	$(ar{l}_p^j e_r) (ar{d}_s q_t^j)$	Q_{duq}	$arepsilon^{lphaeta\gamma}arepsilon_{jk}\left[(d_p^lpha) ight.$	$^{T}Cu_{r}^{\beta}$	$\left[(q_s^{\gamma j})^T C ight.$	
	$Q_{quqd}^{\left(1 ight)}$	$(ar{q}_p^j u_r) arepsilon_{jk} (ar{q}_s^k d_t)$	Q_{qqu}	$arepsilon^{lphaeta\gamma}arepsilon_{jk}\left[(q_p^{lpha j}) ight]$	$^{T}Cq_{r}^{\beta k}$	$\left[(u_s^{\gamma})^T C \right]$	
	$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	Q_{qqq}	$arepsilon^{lphaeta\gamma}arepsilon_{jn}arepsilon_{km}\left[(q_p^lpha) ight]$	$^{j})^{T}Cq_{r}^{\beta}$	$\left[\left(q_{s}^{\gamma m} ight)^{\prime}\right]$	
	$Q_{lequ}^{\left(1 ight)}$	$(ar{l}_p^j e_r) arepsilon_{jk} (ar{q}_s^k u_t)$	Q_{duu}	$arepsilon^{lphaeta\gamma}\left[(d_p^lpha)^T ight.$	$\left[Cu_{r}^{\beta} \right] \left[\right]$	$(u_s^{\gamma})^T Ce_t$	
	$Q_{lequ}^{(3)}$	$(ar{l}_p^j\sigma_{\mu u}e_r)arepsilon_{jk}(ar{q}_s^k\sigma^{\mu u}u_t)$					









Flavor structure of the SMEFT

Viable options

• Subgroups of $U(3)^5$ explored



Viable options: quark and lepton sector

• Subgroups of $U(3)^5$ explored

$U(3)^{5} = U(3)_{q} \times U(3)_{u} \times U(3)_{d} \times U(3)_{\ell} \times U(3)_{e}$

Quark sector

- MFV_Q $\equiv U(3)^3$
- $U(2)^2 \times U(3)_d$
- $U(2)^3 \times U(1)_{b_r}$
- $U(2)^3$

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- $U(2)^3$

 $U(3)^{5} = U(3)_{q} \times U(3)_{u} \times U(3)_{d} \times U(3)_{\ell} \times U(3)_{\ell}$

Lepton sector

- MFV_L $\equiv U(3)^2$
- $U(3)_V, U(2)_V$
- $U(2)^2 \times U(1)^2$, $U(2)^2$
- $U(1)^6$, $U(1)^3$





Viable options: quark and lepton sector

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Quark sector

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- $U(2)^2 \times U(3)_d$
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- $U(2)^3$

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Lepton sector

- MFV_L $\equiv U(3)^2$
- $U(3)_V, U(2)_V$

28 cases

- $U(2)^2 \times U(1)^2$, $U(2)^2$
- $U(1)^6$, $U(1)^3$







Construction of flavor invariants

- MFV_Q example: $G_F = U(3)_q \times U(3)_u \times U(3)_d$
- Fields $q \sim (3,1,1), u \sim (1,3,1), d \sim (1,1,3)$
- Spurions $Y_{\mu} \sim (3, \overline{3}, 1)$ and $Y_{d} \sim (3, 1, \overline{3})$

Construction of flavor invariants

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Fields $q \sim (3,1,1), u \sim (1,3,1), d \sim (1,1,3)$							Examples of 2ψ flavor invariants		
Spi	urions $Y_u \sim$	(3,	$\bar{3},1$) and Y_{c}	$_{l}\sim$	(3,1,3)		$(\bar{q}q)$:	$ \begin{array}{ccc} \mathscr{O}(1): & (\bar{q}q) \\ \mathscr{O}(Y_u^2): & (\bar{q}Y_uY_u^{\dagger}q) \end{array} $	
	X^3		$arphi^6$ and $arphi^4 D^2$		$\psi^2 arphi^3$			$\mathcal{O}(Y_d^2): (\bar{q}Y_dY_d^{\dagger}q)$	
Q_G	$\int ABC \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	Q_{arphi}	$(\varphi^{\dagger}\varphi)^{3}$	$Q_{e\varphi}$	$(\varphi^{\dagger}\varphi)(\bar{l}_{p}e_{r}\varphi)$				
$egin{array}{c} Q_{\widetilde{G}} \ Q_W \end{array}$	$\left[\begin{array}{c} f^{IIDC}G^{I\nu}_{\mu}G^{D\rho}_{\nu}G^{C\mu}_{\rho} \\ \varepsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho} \end{array} \right]$	$egin{array}{c} Q_{arphi \Box} \ Q_{arphi D} \end{array}$	$(arphi^{ert}arphi) \Box (arphi^{ert}arphi) \ \left(arphi^{\dagger} D^{\mu} arphi ight)^{\star} \left(arphi^{\dagger} D_{\mu} arphi ight)$	$egin{array}{c} Q_{uarphi} \ Q_{darphi} \ \end{array}$	$egin{aligned} & (arphi^{\dagger}arphi)(q_p u_rarphi) \ & (arphi^{\dagger}arphi)(ar q_p d_rarphi) \end{aligned}$			$\int \mathcal{O}(1): (\bar{u}u)$	
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$						$(\bar{u}u)$:	$\mathcal{O}(Y_u^2): (\bar{u}Y_u^{\dagger}Y_uu)$	
	$X^2 arphi^2$		$\psi^2 X arphi$		$\psi^2 arphi^2 D$				
$egin{array}{c} Q_{arphi G} \ Q_{arphi \widetilde{G}} \ Q_{arphi W} \ Q_{arphi W} \ Q_{arphi \widetilde{W}} \end{array}$	$\begin{split} \varphi^{\dagger}\varphi G^{A}_{\mu\nu} G^{A\mu\nu} \\ \varphi^{\dagger}\varphi \widetilde{G}^{A}_{\mu\nu} G^{A\mu\nu} \\ \varphi^{\dagger}\varphi W^{I}_{\mu\nu} W^{I\mu\nu} \\ \varphi^{\dagger}\varphi \widetilde{W}^{I}_{\mu\nu} W^{I\mu\nu} \end{split}$	$egin{array}{c} Q_{eW} \ Q_{eB} \ Q_{uG} \ Q_{uW} \end{array}$	$\begin{aligned} &(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W^I_{\mu\nu} \\ &(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu} \\ &(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{\varphi} G^A_{\mu\nu} \\ &(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{\varphi} W^I_{\mu\nu} \end{aligned}$	$egin{array}{ccc} Q^{(1)}_{arphi l} & \ Q^{(3)}_{arphi l} & \ Q_{arphi l} & \ Q_{arphi e} & \ Q^{(1)}_{arphi q} & \ Q^{(1)}_{arph$	$(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{l}_{p}\gamma^{\mu}l_{r})$ $(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}\varphi)(\bar{l}_{p}\tau^{I}\gamma^{\mu}l_{r})$ $(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{e}_{p}\gamma^{\mu}e_{r})$ $(\varphi^{\dagger}i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_{p}\gamma^{\mu}q_{r})$		$(\bar{d}d)$:	$ \begin{bmatrix} \mathcal{O}(1) : & (\bar{d}d) \\ \mathcal{O}(Y_d^2) : & (\bar{d}Y_d^{\dagger}Y_d d) \end{bmatrix} $	
$egin{array}{c c} Q_{arphi B} \ Q_{arphi \widetilde{B}} \ Q_{arphi WB} \ Q_{arphi WB} \ Q_{arphi \widetilde{W} B} \end{array}$	$\begin{array}{c} \varphi^{\dagger}\varphi B_{\mu\nu}B^{\mu\nu} \\ \varphi^{\dagger}\varphi \widetilde{B}_{\mu\nu}B^{\mu\nu} \\ \varphi^{\dagger}\tau^{I}\varphi W^{I}_{\mu\nu}B^{\mu\nu} \\ \varphi^{\dagger}\tau^{I}\varphi \widetilde{W}^{I}_{\mu\nu}B^{\mu\nu} \end{array}$	$egin{array}{c} Q_{uB} \ Q_{dG} \ Q_{dW} \ Q_{dB} \end{array}$	$(\bar{q}_{p}\sigma^{\mu\nu}u_{r})\widetilde{\varphi} B_{\mu\nu}$ $(\bar{q}_{p}\sigma^{\mu\nu}T^{A}d_{r})\varphi G^{A}_{\mu\nu}$ $(\bar{q}_{p}\sigma^{\mu\nu}d_{r})\tau^{I}\varphi W^{I}_{\mu\nu}$ $(\bar{q}_{p}\sigma^{\mu\nu}d_{r})\varphi B_{\mu\nu}$	$egin{array}{c c} Q^{(3)}_{arphi q} & & \ Q_{arphi u} & & \ Q_{arphi u} & & \ Q_{arphi d} & & \ Q_{arphi d} & & \ Q_{arphi u d} & & \ Q_{arphi u d} & & \ Q_{arphi u d} & & \ \end{array}$	$egin{aligned} &(arphi^{\dagger}i\overleftrightarrow{D}_{\mu}^{I}arphi)(ar{q}_{p} au^{I}\gamma^{\mu}q_{r})\ &(arphi^{\dagger}i\overleftrightarrow{D}_{\mu}arphi)(ar{u}_{p}\gamma^{\mu}u_{r})\ &(arphi^{\dagger}i\overleftrightarrow{D}_{\mu}arphi)(ar{d}_{p}\gamma^{\mu}d_{r})\ &i(\widetilde{arphi}^{\dagger}D_{\mu}arphi)(ar{u}_{p}\gamma^{\mu}d_{r}) \end{aligned}$			Greljo, AP, Thomsen	

[2203.09561]





Construction of flavor invariants

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- Spurions $Y_{\mu} \sim (3, \overline{3}, 1)$ and $Y_{d} \sim (3, 1, \overline{3})$

	$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$	$(\bar{L}L)(\bar{R}R)$		
Q_{ll}	$(ar{l}_p\gamma_\mu l_r)(ar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(ar{e}_p \gamma_\mu e_r) (ar{e}_s \gamma^\mu e_t)$	Q_{le}	$(ar{l}_p\gamma_\mu l_r)(ar{e}_s\gamma^\mu e_t)$	
$Q_{qq}^{(1)}$	$(ar{q}_p\gamma_\mu q_r)(ar{q}_s\gamma^\mu q_t)$	Q_{uu}	$(ar{u}_p \gamma_\mu u_r) (ar{u}_s \gamma^\mu u_t)$	Q_{lu}	$(ar{l}_p\gamma_\mu l_r)(ar{u}_s\gamma^\mu u_t)$	
$Q_{qq}^{(3)}$	$(ar q_p \gamma_\mu au^I q_r) (ar q_s \gamma^\mu au^I q_t)$	Q_{dd}	$(ar{d}_p\gamma_\mu d_r)(ar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(ar{l}_p\gamma_\mu l_r)(ar{d}_s\gamma^\mu d_t)$	
$\left \begin{array}{c} Q_{lq}^{(1)} \end{array} ight $	$(ar{l}_p\gamma_\mu l_r)(ar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(ar{e}_p \gamma_\mu e_r) (ar{u}_s \gamma^\mu u_t)$	Q_{qe}	$(ar{q}_p\gamma_\mu q_r)(ar{e}_s\gamma^\mu e_t)$	
$\left \begin{array}{c} Q_{lq}^{(3)} \end{array} ight $	$(ar{l}_p \gamma_\mu au^I l_r) (ar{q}_s \gamma^\mu au^I q_t)$	Q_{ed}	$(ar{e}_p \gamma_\mu e_r) (ar{d}_s \gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(ar{q}_p\gamma_\mu q_r)(ar{u}_s\gamma^\mu u_t)$	
		$Q_{ud}^{(1)}$	$(ar{u}_p \gamma_\mu u_r) (ar{d}_s \gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$\left((ar{q}_p \gamma_\mu T^A q_r) (ar{u}_s \gamma^\mu T^A u_t) \right)$	
		$Q_{ud}^{(8)}$	$(ar{u}_p \gamma_\mu T^A u_r) (ar{d}_s \gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(ar{q}_p\gamma_\mu q_r)(ar{d}_s\gamma^\mu d_t)$	
				$Q_{qd}^{(8)}$	$\left(ar{q}_p \gamma_\mu T^A q_r) (ar{d}_s \gamma^\mu T^A d_t) ight)$	
$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating			
Q_{ledq}	$(ar{l}_p^j e_r)(ar{d}_s q_t^j)$	Q_{duq}	$arepsilon^{lphaeta\gamma}arepsilon_{jk}\left[(d_p^lpha) ight.$	$^{T}Cu_{r}^{\beta}]$	$\left[(q_s^{\gamma j})^T C l_t^k ight]$	
$\left\ \; Q_{quqd}^{(1)} ight.$	$(ar{q}_p^j u_r) arepsilon_{jk} (ar{q}_s^k d_t)$	Q_{qqu}	$arepsilon^{lphaeta\gamma}arepsilon_{jk}\left[(q_p^{lpha j}) ight]$	$)^T C q_r^{\beta k}$	$\left[(u_{s}^{\gamma})^{T}Ce_{t} ight]$	
$\left\ \; Q_{quqd}^{(8)} ight.$	$(ar{q}_p^j T^A u_r) arepsilon_{jk} (ar{q}_s^k T^A d_t)$	$\left \begin{array}{c} Q_{qqq} \end{array} \right \qquad \varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km} \left[(q_p^{\alpha j})^T C q_r^{\beta k} \right] \left[(q_s^{\gamma m})^T C l_t^n \right] \\ \end{array} \right $				
$\left\ ~ Q_{lequ}^{(1)} ight.$	$(ar{l}_p^j e_r) arepsilon_{jk} (ar{q}_s^k u_t)$	Q_{duu}	$ert arepsilon^{lphaeta\gamma} \left[(d_p^lpha)^T ight.$	$\left[Cu_{r}^{\beta} ight] \left[ight]$	$\left[(u_s^\gamma)^T C e_t ight]$	
$Q_{lequ}^{(3)}$	$\left(ar{l}_p^j\sigma_{\mu u}e_r)arepsilon_{jk}(ar{q}_s^k\sigma^{\mu u}u_t) ight)$					

Examples of 4ψ flavor invariants

	_	
	$\mathcal{O}(1)$:	$(\bar{q}_i q^i)(\bar{q}_j q^j), (\bar{q}_i q^j)(\bar{q}_j q^i)$
$(\bar{q}q)(\bar{q}q)$:	$\mathcal{O}(Y_u^2)$:	$(\bar{q}Y_uY_u^{\dagger}q)(\bar{q}q), (\bar{q}_iq^j)(Y_uY_u^{\dagger})_k^i(\bar{q}^kq_j)$
	$\mathcal{O}(Y_d^2)$:	$(\bar{q}Y_dY_d^{\dagger}q)(\bar{q}q), (\bar{q}_iq^j)(Y_dY_d^{\dagger})_k^i(\bar{q}^kq_j)$
	Ø(1):	$(\bar{u}_i u^i)(\bar{u}_j u^j), (\bar{u}_i u^j)(\bar{u}_j u^i)$
$(\bar{u}u)(\bar{u}u)$:	$\mathcal{O}(Y_u^2)$:	$(\bar{u}Y_u^{\dagger}Y_uu)(\bar{u}u), (\bar{u}_iu^j)(Y_u^{\dagger}Y_u)_k^i(\bar{u}_ju^k)$
		$(\bar{d}, d^{i})(\bar{d}, d^{j}) = (\bar{d}, d^{j})(\bar{d}, d^{i})$
$(\bar{u}u)(\bar{u}u)$:	$\mathcal{O}(Y_d^2):$ $\mathcal{O}(1):$ $\mathcal{O}(Y_u^2):$ $\mathcal{O}(1):$	$(q Y_{d} Y_{d}^{\dagger} q)(q q), (q_{i} q^{j})(Y_{d} Y_{d}^{\dagger})_{k}^{i}(q^{\kappa} q_{j})$ $(\bar{u}_{i} u^{i})(\bar{u}_{j} u^{j}), (\bar{u}_{i} u^{j})(\bar{u}_{j} u^{i})$ $(\bar{u} Y_{u}^{\dagger} Y_{u} u)(\bar{u} u), (\bar{u}_{i} u^{j})(Y_{u}^{\dagger} Y_{u})_{k}^{i}(\bar{u}_{j} u^{k})$ $(\bar{d}_{i} d^{i})(\bar{d}_{i} d^{j}), (\bar{d}_{i} d^{j})(\bar{d}_{i} d^{i})$

 $(\bar{d}d)(\bar{d}d)$:

Greljo, AP, Thomsen [2203.09561]

 $\mathcal{O}(Y_d^2): \quad (\bar{d}Y_d^{\dagger}Y_d d)(\bar{d}d), \quad (\bar{d}_i d^j)(Y_d^{\dagger}Y_d)_k^i(\bar{d}_j d^k)$



MF	V_Q	$\mathcal{O}(1)$	<i>O</i> ($Y_u)$	$\mathcal{O}(Y_u^2)$	$\mathcal{O}($	$Y_d)$	$\mathcal{O}(Y_d^2)$	$\mathcal{O}(\mathbf{Y})$	$Y_u Y_d)$	$\mathcal{O}(Y_u^2)$	$Y_d, Y_d^2 Y_u)$	$\mathcal{O}(Y)$	(x_u^3, Y_d^3)
$_{2}/_{2}H^{3}$	Q_{uH}		1	1							1	1	1	1
ψ II	Q_{dH}					1	1				1	1	1	1
a/2 X H	$Q_{u(G,W,B)}$		3	3							3	3	3	3
ψΜΠ	$Q_{d(G,W,B)}$					3	3				3	3	3	3
	$Q_{Hq}^{\left(1,3 ight) }$	2			2			2						
$a/2 H^2 D$	Q_{Hu}	1			1									
ψΠΣ	Q_{Hd}	1						1						
	Q_{Hud}								1	1				
(LL)(LL)	$Q_{qq}^{\left(1,3 ight) }$	4			4			4						
	Q_{uu}	2			2									
(RR)(RR)	Q_{dd}	2						2						
	$Q_{ud}^{\left(1,8 ight) }$	2			2			2						
(LL)(RR)	$Q_{qu}^{\left(1,8 ight) }$	2			6			2						
	$Q_{qd}^{\left(1,8 ight) }$	2			2			6						
(LR)(LR)	$Q_{quqd}^{\left(1,8 ight) }$								4	4				
Tot	al	18	4	4	19	4	4	19	5	5	8	8	8	8







SMEFT	dim-6	operator	class	-

	\$	O(1)	$\mathcal{O}($	$Y_u)$	$\mathcal{O}(Y_u^2)$	$\mathcal{O}($	$Y_d)$	$\mathcal{O}(Y_d^2)$	$\mathcal{O}(Y)$	$Y_u Y_d)$	$\mathcal{O}(Y_u^2 Y_u)$	$(d, Y_d^2 Y_u)$	$\mathcal{O}(Y_u)$	$^3_\iota,Y^3_d)$
$_{2/2}H^{3}$	Q_{uH}		1	1							1	1	1	1
ψ II	Q_{dH}					1	1				1	1	1	1
a/2 X H	$Q_{u(G,W,B)}$		3	3							3	3	3	3
ψ	$Q_{d(G,W,B)}$					3	3				3	3	3	3
	$Q_{Hq}^{\left(1,3 ight) }$	2			2			2						
$a/2H^2D$	Q_{Hu}	1			1									
ψΠΔ	Q_{Hd}	1						1						
	Q_{Hud}								1	1				
(LL)(LL)	$Q_{qq}^{\left(1,3 ight) }$	4			4			4						
	Q_{uu}	2			2									
(RR)(RR)	Q_{dd}	2						2						
	$Q_{ud}^{\left(1,8 ight) }$	2			2			2						
(LL)(RR)	$Q_{qu}^{\left(1,8 ight) }$	2			6			2						
	$Q_{qd}^{\left(1,8 ight) }$	2			2			6						
(LR)(LR)	$Q_{quqd}^{\left(1,8 ight) }$								4	4				
Tota	l	18	4	4	19	4	4	19	5	5	8	8	8	8







$ SMEFT dim-6 operator class \\ (LL)(LL) & Q_{uu}^{(1,8)} & Q_{uu} & 2 & U & U & U & U & U & U & U & U & U$	
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	$\mathcal{O}(Y_u^3,Y_d)$
$SMEFT dim-6 operator class \qquad $. 1
$ \frac{\psi^2 X H}{Q_{d(G,W,B)}} = \begin{bmatrix} Q_{u(G,W,B)} & 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 & 3 & $. 1
$SMEFT dim-6 operator class \qquad $	3
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	3
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	
$\begin{array}{ c c c c c c c c c } \hline Q_{Hud} & & & & & & & & & & & & & & & & & & &$	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	
$egin{array}{ c c c c c c c c c c c c c c c c c c c$	
$egin{array}{ c c c c c c c c c c c c c c c c c c c$	
$egin{array}{ c c c c c c c c c c c c c c c c c c c$	
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	
(1.8)	
$Q_{qd}^{(1,0)}$ 2 6	
$(LR)(LR) Q^{(1,8)}_{quqd} \qquad $	
Total 18 4 4 19 4 4 19 5 5 8 8	3 8

Orders in spurion insertions







	MF	V_Q	$\mathcal{O}(1)$	$\mathcal{O}(Y_u)$	$\mathcal{O}(Y_u^2)$	$\mathcal{O}(Y_d)$	$\mathcal{O}(Y_d^2)$	$\mathcal{O}(Y_uY_d)$	$\mathcal{O}(Y_u^2)$	$Y_d^2 Y_d, Y_d^2 Y_u)$	$\mathcal{O}(Y)$	(x_u^3, Y_d^3)
	a/,2 H3	Q_{uH}		1 1					1	1	1	1
	ψ II	Q_{dH}				1 1			1	1	1	1
	$\psi^2 X H$	$Q_{u(G,W,B)}$		3 3					3	3	3	3
	τ	$Q_{d(G,W,B)}$				3 3			3	3	3	3
SMEFT dim-6 operator class		$Q_{Hq}^{\left(1,3 ight) }$	2		2		2					
	$_{2/2}H^{2}D$	Q_{Hu}	1		1							
	<i>ψ</i> Π <i>D</i>	Q_{Hd}	1				1					
		Q_{Hud}						1 1				
	(LL)(LL)	$Q_{qq}^{\left(1,3 ight) }$	4		4		4					
		Q_{uu}	2		2							
	(RR)(RR)	Q_{dd}	2				2					
		$Q_{ud}^{\left(1,8 ight) }$	2		2		2					
	(LL)(RR)	$Q_{qu}^{\left(1,8 ight) }$	2		6		2					
		$Q_{qd}^{\left(1,8 ight) }$	2		2		6					
	(LR)(LR)	$Q_{quqd}^{(1,8)}$						4 4				
	Tot	al	18	4 4	19	4 4	19	5 5	8	8	8	8

Total number of independent structures at the given order in spurion expansion

Orders in spurion insertions





Repeating the similar exercise both for quark and lepton sector

SME	FT $\mathcal{O}(1)$ terms							L	epton	sector							
(dir	m-6, $\Delta B = 0$)	MF	$^{\circ}\mathrm{V}_{L}$	U(S	$B)_V$	$U(2)^{2}$	$\times U(1)^2$	U($(2)^2$	U(2	$(2)_V$	U($1)^{6}$	U($1)^{3}$	No sy	ymm.
	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
Quark	$\mathrm{U}(2)^2 \times \mathrm{U}(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
Quark	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
sector	$U(2)^{3}$	93	17	100	23	118	17	124	23	132	30	147	17	168	38	321	191
	No symmetry	703	570	734	600	756	591	786	621	818	652	813	612	906	705	1350	1149







Repeating the similar exercise both for quark and lepton sector

																	
SME	FT $\mathcal{O}(1)$ terms							Γ	epton	sector							
(dia	m-6, $\Delta B = 0$)	MF	$^{r}V_{L}$	U(3	$B)_V$	$U(2)^{2}$	$^{2} \times \mathrm{U}(1)^{2}$	U($(2)^2$	U(2	$(2)_V$	U($1)^{6}$	U($1)^{3}$	No sy	ymm.
	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
Quark	$U(2)^2 \times U(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
Quark	$U(2)^3 \times U(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
sector	$U(2)^{3}$	93	17	100	23	118	17	124	23	132	30	147	17	168	38	321	191
	No symmetry	703	570	734	600	756	591	786	621	818	652	813	612	906	705	1350	1149
	•	•										-		-			

47 parameters in the MFV

Greljo, AP, Thomsen [2203.09561]



Repeating the similar exercise both for quark and lepton sector

SME	FT $\mathcal{O}(1)$ terms							L	epton	sector							
(di	m-6, $\Delta B = 0$)	MF	$^{\circ}\mathrm{V}_{L}$	U(3	$B)_V$	$U(2)^{2}$	$\times U(1)^2$	U(2	$(2)^2$	U(2	$(2)_V$	U($1)^{6}$	U($1)^{3}$	No sy	ymm.
	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
Quark	$\mathrm{U}(2)^2 \times \mathrm{U}(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
Quark	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
sector	$U(2)^{3}$	93	17	100	23	118	17	124	23	132	30	147	17	168	38	321	191
	No symmetry	703	570	734	600	756	591	786	621	818	652	813	612	906	705	1350	1149

47 parameters in the MFV

Faroughy, Isidori, Wilsch, Yamamoto [2005.05366]

147 parameters in $U(2)^5$





Repeating the similar exercise both for quark and lepton sector

SME	FT $\mathcal{O}(1)$ terms							L	epton	sector							
(dii	m-6, $\Delta B = 0$)	MF	$^{\circ}\mathrm{V}_{L}$	U(3	$B)_V$	$U(2)^2$	$^2 \times \mathrm{U}(1)^2$	U($(2)^2$	U(2	$(2)_V$	U($1)^{6}$	U($1)^{3}$	No sy	vmm.
	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
Quark	$\mathrm{U}(2)^2 \times \mathrm{U}(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
Guark	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
sector	$U(2)^{3}$	93	17	100	23	118	17	124	23	132	30	147	17	168	38	321	191
	No symmetry	703	570	734	600	756	591	786	621	818	652	813	612	906	705	1350	1149
	47 para	ameter	rs in th	ne MF\	/												
											_						
							147 pa	arame	ters in	$U(2)^{5}$							7
						Farou	ıqhy, İsidori.	Wilsch	, Yamai	moto [2	005.053	366]	2	499 p	arame	ters wit	hout any

Greljo, AP, Thomsen [2203.09561]



ymmetries





Leading directions in the SMEFT

Leading directions: MFV basis

SME	FT $\mathcal{O}(1)$ terms							L	epton	sector							
(din	m-6, $\Delta B = 0$)	MF	V_L	U(:	$B)_V$	$U(2)^{2}$	$2 \times U(1)^2$	U($(2)^2$	U(2	$(2)_V$	U($1)^{6}$	U($1)^{3}$	No sy	ymm.
	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
Quark	$\mathrm{U}(2)^2 \times \mathrm{U}(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
Quark	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
sector	$U(2)^{3}$	93	17	100	23	118	17	124	23	132	30	147	17	168	38	321	191
	No symmetry	703	570	734	600	756	591	786	621	818	652	813	612	906	705	1350	1149

47 parameters in the MFV

Greljo, AP [2305.08898]

Class	Label	Operator	Label	Operator
	$\mathcal{O}^{D}_{\ell\ell}$	$(ar{\ell}_i\gamma^\mu\ell^i)(ar{\ell}_j\gamma_\mu\ell^j)$	$\mathcal{O}_{\ell q}^{(1)}$	$(ar{\ell}_i\gamma^\mu\ell^i)(ar{q}_j\gamma_\mu q^j)$
$(\bar{L}L)(\bar{L}L)$	$\mathcal{O}^E_{\ell\ell}$	$(ar{\ell}_i \gamma^\mu \ell^j) (ar{\ell}_j \gamma_\mu \ell^i)$	$\mathcal{O}_{\ell q}^{(ar{3})}$	$(ar{\ell}_i\gamma^\mu\sigma^a\ell^i)(ar{q}_j\gamma_\mu\sigma^aq^j)$
()()	$\mathcal{O}_{qq}^{(1)D}$	$(ar q_i\gamma^\mu q^i)(ar q_j\gamma_\mu q^j)$	$\mathcal{O}_{qq}^{(3)D}$	$(ar q_i\gamma^\mu\sigma^a q^i)(ar q_j\gamma_\mu\sigma^a q^j)$
	$\mathcal{O}_{qq}^{(1)E}$	$(ar q_i\gamma^\mu q^j)(ar q_j\gamma_\mu q^i)$	$\mathcal{O}_{qq}^{(3)E}$	$(ar q_i\gamma^\mu\sigma^a q^j)(ar q_j\gamma_\mu\sigma^a q^i)$
	\mathcal{O}_{ee}	$(ar{e}_i\gamma^\mu e^i)(ar{e}_j\gamma_\mu e^j)$	\mathcal{O}_{dd}^{D}	$(ar{d}_i\gamma^\mu d^i)(ar{d}_j\gamma_\mu d^j)$
	\mathcal{O}_{uu}^D	$(ar{u}_i\gamma^\mu u^i)(ar{u}_j\gamma_\mu u^j)$	\mathcal{O}^E_{dd}	$(ar{d_i}\gamma^\mu d^j)(ar{d_j}\gamma_\mu d^i)$
$(\bar{R}R)(\bar{R}R)$	\mathcal{O}^E_{uu}	$(ar{u}_i\gamma^\mu u^j)(ar{u}_j\gamma_\mu u^i)$	$\mathcal{O}_{ud}^{(1)}$	$(ar{u}_i\gamma^\mu u^i)(ar{d}_j\gamma_\mu d^j)$
	\mathcal{O}_{eu}	$(ar{e}_i\gamma^\mu e^i)(ar{u}_j\gamma_\mu u^j)$	$\mathcal{O}_{ud}^{(8)}$	$(ar{u}_i\gamma^\mu T^A u^i)(ar{d}_j\gamma_\mu T^A d^j)$
	\mathcal{O}_{ed}	$(ar{e}_i\gamma^\mu e^i)(ar{d}_j\gamma_\mu d^j)$		
	$\mathcal{O}_{\ell e}$	$(ar{\ell}_i\gamma^\mu\ell^i)(ar{e}_j\gamma_\mu e^j)$	$\mathcal{O}_{qu}^{(1)}$	$(ar q_i\gamma^\mu q^i)(ar u_j\gamma_\mu u^j)$
$(\overline{I}I)(\overline{D}D)$	\mathcal{O}_{qe}	$(ar q_i \gamma^\mu q^i) (ar e_j \gamma_\mu e^j)$	${\cal O}_{qu}^{(8)}$	$(ar{q}_i\gamma^\mu T^A q^i)(ar{u}_j\gamma_\mu T^A u^j)$
(LL)(hh)	$\mathcal{O}_{\ell u}$	$(ar{\ell}_i\gamma^\mu\ell^i)(ar{u}_j\gamma_\mu u^j)$	$\mathcal{O}_{qd}^{(1)}$	$(ar q_i\gamma^\mu q^i)(ar d_j\gamma_\mu d^j)$
	$\mathcal{O}_{\ell d}$	$(ar{\ell}_i\gamma^\mu\ell^i)(ar{d}_j\gamma_\mu d^j)$	$\mathcal{O}_{qd}^{(8)}$	$(ar q_i \gamma^\mu T^A q^i) (ar d_j \gamma_\mu T^A d^j)$
	$\mathcal{O}_{\phi\ell}^{(1)}$	$(\phi^\dagger i \stackrel{\leftrightarrow}{D}_\mu \phi) (ar{\ell}_i \gamma^\mu \ell^i)$	$\mathcal{O}_{\phi e}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (ar{e}_i \gamma^\mu e^i)$
$d^2 d^2 D$	$\mathcal{O}_{\phi\ell}^{(3)}$	$(\phi^\dagger i \overset{\leftrightarrow}{D^a_\mu} \phi) (ar{\ell}_i \gamma^\mu \sigma^a \ell^i)$	$\mathcal{O}_{\phi u}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (ar{u}_i \gamma^\mu u^i)$
ψψD	$\mathcal{O}_{\phi q}^{(1)}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (ar{q}_i \gamma^\mu q^i)$	$\mathcal{O}_{\phi d}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (ar{d}_i \gamma^\mu d^i)$
	$\mathcal{O}_{\phi q}^{(3)}$	$(\phi^\dagger i \stackrel{\leftrightarrow}{D^a_\mu} \phi) (ar{q}_i \gamma^\mu \sigma^a q^i)$		

Class	Label	Operator	Label	Operator
X^3	\mathcal{O}_W	$arepsilon_{abc} W^{a u}_{\mu} W^{b ho}_{ u} W^{c\mu}_{ ho}$	\mathcal{O}_G	$f_{ABC}G^{A u}_{\mu}G^{B ho}_{ u}G^{C\mu}_{ ho}$
Loop generated	${\mathcal O}_{ ilde W}$	$\varepsilon_{abc} \tilde{W}^{a\nu}_{\mu} W^{b\rho}_{\nu} W^{c\mu}_{ ho}$	$\mathcal{O}_{ ilde{G}}$	$f_{ABC} ilde{G}^{A u}_{\mu} G^{B ho}_{ u} G^{C\mu}_{ ho}$
ϕ^6	\mathcal{O}_{ϕ}	$(\phi^\dagger \phi)^3$		
$\phi^4 D^2$	$\mathcal{O}_{\phi\square}$	$(\phi^\dagger \phi) \Box (\phi^\dagger \phi)$	$\mathcal{O}_{\phi D}$	$(\phi^\dagger D_\mu \phi) [(D^\mu \phi)^\dagger \phi]$
	$\mathcal{O}_{\phi B}$	$(\phi^{\dagger}\phi)B_{\mu u}B^{\mu u}$	$\mathcal{O}_{\phi WB}$	$(\phi^{\dagger}\sigma^{a}\phi)W^{a}_{\mu u}B^{\mu u}$
$X^2 \phi^2$	${\cal O}_{\phi ilde{B}}$	$(\phi^{\dagger}\phi) ilde{B}_{\mu u}B^{\mu u}$	$\mathcal{O}_{\phi ilde{W}B}$	$(\phi^{\dagger}\sigma^{a}\phi) ilde{W}^{a}_{\mu u}B^{\mu u}$
Loop generated	$\mathcal{O}_{\phi W}$	$(\phi^\dagger \phi) W^a_{\mu u} W^{a\mu u}$	$\mathcal{O}_{\phi G}$	$(\phi^\dagger \phi) G^A_{\mu u} G^{A\mu u}$
	$\mathcal{O}_{\phi ilde W}$	$(\phi^\dagger \phi) ilde W^a_{\mu u} W^{a\mu u}$	${\cal O}_{\phi ilde{G}}$	$(\phi^\dagger \phi) ilde{G}^A_{\mu u} G^{A\mu u}$
Class	Label	Operator	Label	Operator
a/,2,d ³	$[\mathcal{O}_{e\phi}]_{i_\ell}^{j_e}$	$(\phi^{\dagger}\phi)(ar{\ell}_{i_{\ell}}\phi e^{j_{e}})$		
ψΨ	$[\mathcal{O}_{d\phi}]_{i_q}^{j_d}$	$(\phi^{\dagger}\phi)(ar{q}_{i_{q}}\phi d^{j_{d}})$	$[\mathcal{O}_{u\phi}]_{i_q}^{j_u}$	$(\phi^{\dagger}\phi)(ar{q}_{i_q} ilde{\phi}u^{j_u})$
	$[\mathcal{O}_{eB}]_{i_\ell}^{j_e}$	$(ar{\ell}_{i_\ell}\sigma^{\mu u}e^{j_e})\phi B_{\mu u}$	$[\mathcal{O}_{eW}]_{i_\ell}^{j_e}$	$(ar{\ell}_{i_\ell}\sigma^{\mu u}e^{j_e})\sigma^a\phi W^a_{\mu u}$
$\psi^2 X \phi$	$[\mathcal{O}_{uB}]_{i_q}^{j_u}$	$(ar q_{i_q}\sigma^{\mu u}u^{j_u}) ilde \phi B_{\mu u}$	$[\mathcal{O}_{uW}]_{i_q}^{j_u}$	$(ar{q}_{i_q}\sigma^{\mu u}u^{j_u})\sigma^a ilde{\phi}W^a_{\mu u}$
Loop generated	$[\mathcal{O}_{dB}]_{i_q}^{j_d}$	$(ar q_{i_q}\sigma^{\mu u}d^{j_d})\phi B_{\mu u}$	$[\mathcal{O}_{dW}]_{i_q}^{j_d}$	$(ar{q}_{i_q}\sigma^{\mu u}d^{j_d})\sigma^a\phi W^a_{\mu u}$
	$[\mathcal{O}_{uG}]_{i_q}^{j_u}$	$(\bar{q}_{i_q}\sigma^{\mu u}T^A u^{j_u})\tilde{\phi}G^A_{\mu u}$	$[\mathcal{O}_{dG}]_{i_q}^{j_d}$	$(ar{q}_{i_q}\sigma^{\mu u}T^Ad^{j_d})\phi G^A_{\mu u}$



Leading directions: MFV basis

SMEFT $\mathcal{O}(1)$ terms		Lepton sector														
(di	$(\text{dim-6},\Delta B=0)$		$MFV_L = U(3)_V$		$\begin{array}{ c c } U(2)^2 \times U(1)^2 \end{array}$		$U(2)^{2}$		$\mathrm{U}(2)_V$		$U(1)^{6}$		$U(1)^{3}$			
	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	
Quark	$U(2)^2 \times U(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	
Quark	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	
sector	$U(2)^{3}$	93	17	100	23	118	17	124	23	132	30	147	17	168	38	
	No symmetry	703	570	734	600	756	591	786	621	818	652	813	612	906	705	5



- In a renormalizable UV completion, operators be generated at tree-level
- What are all tree-level UV completions that match to these operators?

Greljo, AP [2305.08898]

No sy	ymm.
207	132
281	169
305	175
321	191
350	1149

Class	Label	Operator	Label	Operator
	$\mathcal{O}^{D}_{\ell\ell}$	$(ar{\ell}_i\gamma^\mu\ell^i)(ar{\ell}_j\gamma_\mu\ell^j)$	$\mathcal{O}_{\ell q}^{(1)}$	$(ar{\ell}_i\gamma^\mu\ell^i)(ar{q}_j\gamma_\mu q^j)$
$(\bar{L}L)(\bar{L}L)$	$\mathcal{O}^E_{\ell\ell}$	$(ar{\ell}_i\gamma^\mu\ell^j)(ar{\ell}_j\gamma_\mu\ell^i)$	$\mathcal{O}_{\ell q}^{(3)}$	$(ar{\ell}_i\gamma^\mu\sigma^a\ell^i)(ar{q}_j\gamma_\mu\sigma^aq^j)$
(22)(22)	$\mathcal{O}_{qq}^{(1)D}$	$(ar q_i \gamma^\mu q^i) (ar q_j \gamma_\mu q^j)$	$\mathcal{O}_{qq}^{(3)D}$	$(ar q_i\gamma^\mu\sigma^a q^i)(ar q_j\gamma_\mu\sigma^a q^j)$
	$\mathcal{O}_{qq}^{(1)E}$	$(ar q_i\gamma^\mu q^j)(ar q_j\gamma_\mu q^i)$	${\cal O}_{qq}^{(3)E}$	$(ar q_i\gamma^\mu\sigma^a q^j)(ar q_j\gamma_\mu\sigma^a q^i)$
	\mathcal{O}_{ee}	$(ar{e}_i\gamma^\mu e^i)(ar{e}_j\gamma_\mu e^j)$	\mathcal{O}^{D}_{dd}	$(ar{d}_i\gamma^\mu d^i)(ar{d}_j\gamma_\mu d^j)$
	\mathcal{O}^{D}_{uu}	$(ar{u}_i\gamma^\mu u^i)(ar{u}_j\gamma_\mu u^j)$	\mathcal{O}^E_{dd}	$(ar{d}_i\gamma^\mu d^j)(ar{d}_j\gamma_\mu d^i)$
$(\bar{R}R)(\bar{R}R)$	\mathcal{O}^E_{uu}	$(ar{u}_i\gamma^\mu u^j)(ar{u}_j\gamma_\mu u^i)$	$\mathcal{O}_{ud}^{(1)}$	$(ar{u}_i\gamma^\mu u^i)(ar{d}_j\gamma_\mu d^j)$
	\mathcal{O}_{eu}	$(ar{e}_i\gamma^\mu e^i)(ar{u}_j\gamma_\mu u^j)$	$\mathcal{O}_{ud}^{(8)}$	$(ar{u}_i\gamma^\mu T^A u^i)(ar{d}_j\gamma_\mu T^A d^j)$
	\mathcal{O}_{ed}	$(ar{e}_i\gamma^\mu e^i)(ar{d}_j\gamma_\mu d^j)$		
	$\mathcal{O}_{\ell e}$	$(ar{\ell}_i\gamma^\mu\ell^i)(ar{e}_j\gamma_\mu e^j)$	$\mathcal{O}_{qu}^{(1)}$	$(ar q_i\gamma^\mu q^i)(ar u_j\gamma_\mu u^j)$
$(\overline{I}I)(\overline{D}D)$	\mathcal{O}_{qe}	$(ar q_i\gamma^\mu q^i)(ar e_j\gamma_\mu e^j)$	${\cal O}_{qu}^{(8)}$	$(ar q_i \gamma^\mu T^A q^i) (ar u_j \gamma_\mu T^A u^j)$
(LL)(hh)	$\mathcal{O}_{\ell u}$	$(ar{\ell}_i\gamma^\mu\ell^i)(ar{u}_j\gamma_\mu u^j)$	$\mathcal{O}_{qd}^{(1)}$	$(ar q_i\gamma^\mu q^i)(ar d_j\gamma_\mu d^j)$
	$\mathcal{O}_{\ell d}$	$(ar{\ell}_i\gamma^\mu\ell^i)(ar{d}_j\gamma_\mu d^j)$	$\mathcal{O}_{qd}^{(8)}$	$(ar{q}_i\gamma^\mu T^A q^i)(ar{d}_j\gamma_\mu T^A d^j)$
	$\mathcal{O}_{\phi\ell}^{(1)}$	$(\phi^\dagger i \overset{\leftrightarrow}{D}_\mu \phi) (ar{\ell}_i \gamma^\mu \ell^i)$	$\mathcal{O}_{\phi e}$	$(\phi^\dagger i \stackrel{\leftrightarrow}{D}_\mu \phi) (ar{e}_i \gamma^\mu e^i)$
$d^2 \star^2 D$	$\mathcal{O}_{\phi\ell}^{(3)}$	$(\phi^\dagger i \stackrel{\leftrightarrow}{D^a_\mu} \phi) (ar{\ell}_i \gamma^\mu \sigma^a \ell^i)$	$\mathcal{O}_{\phi u}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (ar{u}_i \gamma^\mu u^i)$
$\psi \phi^{-}D$	$\mathcal{O}_{\phi q}^{(1)}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (ar{q}_i \gamma^\mu q^i)$	$\mathcal{O}_{\phi d}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (ar{d}_i \gamma^\mu d^i)$
	${\cal O}_{\phi q}^{(3)}$	$(\phi^{\dagger}i \overset{\leftrightarrow}{D_{\mu}^{a}} \phi) (\bar{q}_{i} \gamma^{\mu} \sigma^{a} q^{i})$		

Class	Label	Operator	Label	Operator
X^3	\mathcal{O}_W	$arepsilon_{abc} W^{a u}_{\mu} W^{b ho}_{ u} W^{c\mu}_{ ho}$	\mathcal{O}_G	$f_{ABC}G^{A u}_{\mu}G^{B ho}_{ u}G^{C\mu}_{ ho}$
Loop generated	${\cal O}_{ ilde W}$	$arepsilon_{abc} ilde W^{a u}_{\mu} W^{b ho}_{ u} W^{c\mu}_{ ho}$	$\mathcal{O}_{ ilde{G}}$	$f_{ABC} ilde{G}^{A u}_{\mu} G^{B ho}_{ u} G^{C\mu}_{ ho}$
ϕ^6	\mathcal{O}_{ϕ}	$(\phi^\dagger \phi)^3$		
$\phi^4 D^2$	$\mathcal{O}_{\phi\square}$	$(\phi^\dagger \phi) \Box (\phi^\dagger \phi)$	$\mathcal{O}_{\phi D}$	$(\phi^\dagger D_\mu \phi) [(D^\mu \phi)^\dagger \phi]$
	$\mathcal{O}_{\phi B}$	$(\phi^{\dagger}\phi)B_{\mu u}B^{\mu u}$	$\mathcal{O}_{\phi WB}$	$(\phi^{\dagger}\sigma^{a}\phi)W^{a}_{\mu u}B^{\mu u}$
$X^2 \phi^2$	$\mathcal{O}_{\phi ilde{B}}$	$(\phi^{\dagger}\phi) ilde{B}_{\mu u}B^{\mu u}$	$\mathcal{O}_{\phi ilde{W}B}$	$(\phi^{\dagger}\sigma^{a}\phi) ilde{W}^{a}_{\mu u}B^{\mu u}$
Loop generated	$\mathcal{O}_{\phi W}$	$(\phi^{\dagger}\phi)W^{a}_{\mu u}W^{a\mu u}$	$\mathcal{O}_{\phi G}$	$(\phi^\dagger \phi) G^A_{\mu u} G^{A\mu u}$
	$\mathcal{O}_{\phi ilde W}$	$(\phi^{\dagger}\phi) ilde{W}^{a}_{\mu u}W^{a\mu u}$	$\mathcal{O}_{\phi ilde{G}}$	$(\phi^\dagger \phi) ilde{G}^A_{\mu u} G^{A\mu u}$
Class	Label	Operator	Label	Operator
a/,2 d3	$[\mathcal{O}_{e\phi}]_{i_\ell}^{j_e}$	$(\phi^{\dagger}\phi)(ar{\ell}_{i_{\ell}}\phi e^{j_{e}})$		
$\psi \ \psi$	$\left[\mathcal{O}_{d\phi} ight]_{i_q}^{j_d}$	$(\phi^{\dagger}\phi)(ar{q}_{i_{q}}\phi d^{j_{d}})$	$[\mathcal{O}_{u\phi}]_{i_q}^{j_u}$	$(\phi^{\dagger}\phi)(ar{q}_{i_{q}} ilde{\phi}u^{j_{u}})$
	$[\mathcal{O}_{eB}]_{i_\ell}^{j_e}$	$(ar{\ell}_{i_\ell}\sigma^{\mu u}e^{j_e})\phi B_{\mu u}$	$[\mathcal{O}_{eW}]_{i_\ell}^{j_e}$	$(ar{\ell}_{i_\ell}\sigma^{\mu u}e^{j_e})\sigma^a\phi W^a_{\mu u}$
$\psi^2 X \phi$	$[\mathcal{O}_{uB}]_{i_q}^{j_u}$	$(ar q_{i_q}\sigma^{\mu u}u^{j_u}) ilde \phi B_{\mu u}$	$[\mathcal{O}_{uW}]_{i_q}^{j_u}$	$(ar q_{i_q}\sigma^{\mu u}u^{j_u})\sigma^a ilde \phi W^a_{\mu u}$
Loop generated	$[\mathcal{O}_{dB}]_{i_{\sigma}}^{j_{d}}$	$(ar{q}_{i_q}\sigma^{\mu u}d^{j_d})\phi B_{\mu u}$	$[\mathcal{O}_{dW}]_{i_q}^{j_d}$	$(ar q_{i_q}\sigma^{\mu u}d^{j_d})\sigma^a\phi W^a_{\mu u}$
			7	





Leading directions: SM + 1 NP

Assume the extension of the Standard Model by one New Physics mediator







Leading directions: SM + 1 NP

Assume the extension of the Standard Model by one New Physics mediator



	\mathcal{S}_1 (1, 1)	\mathcal{S}_2 $(1, 1)$	φ (1.2),	Ξ (1.3)	Ξ_1	Θ_1	Θ_3 (1.4)
	$(1, 1)_1$	$(1,1)_2$	$(1, 2)\frac{1}{2}$		(1,0)1	$(1, 4)\frac{1}{2}$	$(1, 4)\frac{3}{2}$
1	$\omega_2 \ (3,1)_{\underline{2}}$	$\omega_4 \ (3,1)_4$	Π_1 $(3,2)_{1}$	Π_7 (3,2) ₇	$rac{\zeta}{(3,3)_{-1}}$		
3	Q	()	$\gamma_{\overline{6}}$	<u>т</u>	\(\cdot \) - \(\frac{1}{3} \) \)		
	$(6,1)_{-\frac{2}{2}}$	$(6,1)_{\frac{4}{2}}$	$(6,3)_{\frac{1}{2}}$	$(8,2)_{\frac{1}{2}}$			
	3	3	3	2			
	E	Δ_1	Δ_3	Σ	\sum_{1}		
	$(1,1)_{-1}$	$(1,2)_{-\frac{1}{2}}$	$(1,2)_{-\frac{3}{2}}$	$(1,3)_0$	$(1,3)_{-1}$	L	
	D	Q_1	Q_5	Q_7	T_1	T_2	
	$(3,1)_{-rac{1}{3}}$	$(3,2)_{rac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$_{\frac{5}{6}}$ $(3,2)_{\frac{7}{6}}$	$(3,3)_{-rac{1}{3}}$	(3,3)	$\frac{2}{3}$
	\mathcal{B}_1	\mathcal{W}	\mathcal{W}_1	G	\mathcal{G}_1	${\cal H}$	\mathcal{L}_1
	$(1,1)_1$	$\left(1,3 ight)_{0}$	$(1,3)_1$	$(8,1)_0$	$(8,1)_1$	$(8,3)_0$	$(1,2)_{rac{1}{2}}$
	\mathcal{U}_2	\mathcal{U}_5	\mathcal{Q}_1	\mathcal{Q}_5	X	\mathcal{Y}_1	\mathcal{Y}_5
$\frac{3}{2}$	$(3,1)_{rac{2}{3}}$	$(3,1)_{rac{5}{3}}$	$(3,2)_{rac{1}{6}}$	$(3,2)_{-rac{5}{6}}$	$(3,3)_{rac{2}{3}}$	$(ar{6},2)_{rac{1}{6}}$	$(ar{6},2)_{-rac{5}{6}}$

De Blas, Criado, Perez-Victoria, Santiago [1711.10391]













$\omega_4 \sim (3,1)_{-4/3} \qquad -\mathcal{L}_S \supset [y_{\omega_4}^{ed}]_{rij} \omega_{4r}^{\dagger} \bar{e}_i^c d_j + [y_{\omega_4}^{uu}]_{rij} \omega_4^{\alpha\dagger} \varepsilon_{\alpha\beta\gamma} \bar{u}_i^{\beta} u_j^{\gamma c} + \mathrm{h.c.}$



















Greljo, AP [2305.08898]






Leading directions: Results

Field	Irrep	Normalization	Operator		
$\mathcal{S}_1 \sim (1, 1)_1$	3_ℓ	$ y_{\mathcal{S}_1} ^2/M_{\mathcal{S}_1}^2$	$\mathcal{O}^{D}_{\ell\ell} - \mathcal{O}^{E}_{\ell\ell}$		
$\mathcal{S}_2 \sim (1, 1)_2$	$ar{6}_{e}$	$ y_{\mathcal{S}_2} ^2/(2M_{\mathcal{S}_2}^2)$	\mathcal{O}_{ee}		
	$(ar{3}_e, 3_\ell)$	$- y^e_arphi ^2/(2M^2_arphi)$	$\mathcal{O}_{\ell e}$		
$arphi \sim (1,2)_{rac{1}{2}}$	$(ar{3}_d, 3_q)$	$- y^d_arphi ^2/(6M^2_arphi)$	${\cal O}_{qd}^{(1)}+6{\cal O}_{qd}^{(8)}$		
	$(ar{3}_q, 3_u)$	$- y^u_arphi ^2/(6M^2_arphi)$	$\mathcal{O}_{qu}^{(1)}+6\mathcal{O}_{qu}^{(8)}$		
$\Xi_1 \sim (1, 3)_1$	$ar{6}_\ell$	$\left y_{\Xi_{1}} ight ^{2}/(2M_{\Xi_{1}}^{2})$	$\mathcal{O}^{D}_{\ell\ell} + \mathcal{O}^{E}_{\ell\ell}$		
	$({f 3}_q,{f 3}_\ell)$	$ y_{\omega_1}^{q\ell} ^2/(4M_{\omega_1}^2)$	$\mathcal{O}_{\ell q}^{(1)}-\mathcal{O}_{\ell q}^{(3)}$		
(9.1)	$(3_e,3_u)$	$ y^{eu}_{\omega_1} ^2/(2M^2_{\omega_1})$	\mathcal{O}_{eu}		
$\omega_1 \sim (3, 1)_{-\frac{1}{3}}$	$ar{6}_q$	$ y^{qq}_{\omega_1} ^2/(4M^2_{\omega_1})$	$\mathcal{O}_{qq}^{(1)D}-\mathcal{O}_{qq}^{(3)D}+\mathcal{O}_{qq}^{(1)E}-\mathcal{O}_{qq}^{(3)E}$		
	$(ar{3}_d,ar{3}_u)$	$ y^{du}_{\omega_1} ^2/(3M^2_{\omega_1})$	$\mathcal{O}_{ud}^{(1)}-3\mathcal{O}_{ud}^{(8)}$		
$\omega_2 \sim ({f 3},{f 1})_{2\over 3}$	3_d	$ y_{\omega_2} ^2/M_{\omega_2}^2$	$\mathcal{O}^{D}_{dd} - \mathcal{O}^{E}_{dd}$		
(9.1)	$(3_e,3_d)$	$ y^{ed}_{\omega_4} ^2/(2M^2_{\omega_4})$	\mathcal{O}_{ed}		
$\omega_4 \sim (3, 1)_{-\frac{4}{3}}$	3_{u}	$ y^{uu}_{\omega_4} ^2/M^2_{\omega_4}$	$\mathcal{O}^{D}_{uu}-\mathcal{O}^{E}_{uu}$		
$\Pi_1 \sim ({\bf 3},{\bf 2})_{\frac{1}{6}}$	$(ar{3}_\ell, 3_d)$	$- y_{\Pi_1} ^2/(2M_{\Pi_1}^2)$	${\cal O}_{\ell d}$		
	$(ar{3}_\ell, 3_u)$	$-\left y_{\Pi_{7}}^{\ell u} ight ^{2}/(2M_{\Pi_{7}}^{2})$	$\mathcal{O}_{\ell u}$		
$\Pi_7 \sim ({f 3},{f 2})_{7\over 6}$	$(ar{3}_e, 3_q)$	$- y_{\Pi_7}^{qe} ^2/(2M_{\Pi_7}^2)$	\mathcal{O}_{qe}		
ć (9.9)	$({f 3}_q,{f 3}_\ell)$	$ y_\zeta^{q\ell} ^2/(4M_\zeta^2)$	$3 {\cal O}_{\ell q}^{(1)} + {\cal O}_{\ell q}^{(3)}$		
$\zeta \sim (\mathbf{a}, \mathbf{a})_{-\frac{1}{3}}$	3_q	$ y_\zeta^{qq} ^2/(2M_\zeta^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$		
	$(3_u,3_d)$	$ y^{ud}_{\Omega_1} ^2/(6M^2_{\Omega_1})$	$2\mathcal{O}_{ud}^{(1)}+3\mathcal{O}_{ud}^{(8)}$		
$\Omega_1 \sim (6, 1)_{rac{1}{3}}$	$ar{3}_q$	$ y^{qq}_{\Omega_1} ^2/(4M^2_{\Omega_1})$	${\cal O}_{qq}^{(1)D} - {\cal O}_{qq}^{(3)D} - {\cal O}_{qq}^{(1)E} + {\cal O}_{qq}^{(3)E}$		
$\Omega_2 \sim (6, 1)_{-rac{2}{3}}$	6_d	$ y_{\Omega_2} ^2/(4M_{\Omega_2}^2)$	$\mathcal{O}^{D}_{dd} + \mathcal{O}^{E}_{dd}$		
$\Omega_4 \sim ({f 6},{f 1})_{4\over 3}$	6_{u}	$ y_{\Omega_4} ^2/(4M_{\Omega_4}^2)$	$\mathcal{O}^{D}_{uu} + \mathcal{O}^{E}_{uu}$		
$\Upsilon \sim ({f 6},{f 3})_{1\over 3}$	6_q	$ y_{\Upsilon} ^2/(8M_{\Upsilon}^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} + 3\mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$		
	$(ar{3}_q, 3_u)$	$- y_{\Phi}^{qu} ^2/(18M_{\Phi}^2)$	$4 {\cal O}_{qu}^{(1)} - 3 {\cal O}_{qu}^{(8)}$		
$\Phi \sim ({f 8},{f 2})_{1\over 2}$	$(ar{3}_d, 3_q)$	$- y_{\Phi}^{dq} ^2/(18M_{\Phi}^2)$	$4 {\cal O}_{qd}^{(1)} - 3 {\cal O}_{qd}^{(8)}$		

Field	Irrep	Normalization	Operator	
	8_{ℓ}	$-(g^\ell_{\cal B})^2/(12M^2_{\cal B})$	$3\mathcal{O}^E_{\ell\ell}-\mathcal{O}^D_{\ell\ell}$	
	8_{e}	$-(g^e_{\mathcal{B}})^2/(6M^2_{\mathcal{B}})$	\mathcal{O}_{ee}	
$\mathcal{B} \sim (1, 1)_0$	8_q	$-(g^q_{\mathcal{B}})^2/(12M^2_{\mathcal{B}})$	$3\mathcal{O}_{qq}^{(1)E}-\mathcal{O}_{qq}^{(1)D}$	
	8_{u}	$-(g^u_{\cal B})^2/(12M^2_{\cal B})$	$3\mathcal{O}^E_{uu}-\mathcal{O}^D_{uu}$	
	8_{d}	$-(g^d_{\mathcal{B}})^2/(12M^2_{\mathcal{B}})$	$3\mathcal{O}^E_{dd}-\mathcal{O}^D_{dd}$	
$\mathcal{B}_1 \sim (1, 1)_1$	$(ar{3}_d, 3_u)$	$- g^{du}_{{\cal B}_1} ^2/(3M^2_{{\cal B}_1})$	${\cal O}_{ud}^{(1)}+6{\cal O}_{ud}^{(8)}$	
(1,0)	8_q	$-(g^q_{{\cal W}})^2/(48M^2_{{\cal W}})$	$3\mathcal{O}_{qq}^{(3)E}-\mathcal{O}_{qq}^{(3)D}$	
$\mathcal{W} \sim (1, 3)_0$	8_{ℓ}	$(g^\ell_\mathcal{W})^2/(48M^2_\mathcal{W})$	$5\mathcal{O}^E_{\ell\ell}-7\mathcal{O}^D_{\ell\ell}$	
$\mathcal{L}_3 \sim (1, 2)_{-rac{3}{2}}$	$(3_e,3_\ell)$	$\left g_{\mathcal{L}_3} ight ^2/M_{\mathcal{L}_3}^2$	$\mathcal{O}_{\ell e}$	
	$(ar{3}_e, 3_d)$	$- g^{ed}_{\mathcal{U}_2} ^2/M^2_{\mathcal{U}_2}$	\mathcal{O}_{ed}	
$\mathcal{U}_2\sim (3,1)_{rac{2}{3}}$	$(ar{3}_\ell, 3_q)$	$- g_{\mathcal{U}_2}^{\ell q} ^2/(2M_{\mathcal{U}_2}^2)$	$\mathcal{O}_{\ell q}^{(1)} + \mathcal{O}_{\ell q}^{(3)}$	
$\mathcal{U}_5 \sim (3, 1)_{rac{5}{3}}$	$(ar{3}_e, 3_u)$	$- g_{\mathcal{U}_5} ^2/M_{\mathcal{U}_5}^2$	\mathcal{O}_{eu}	
(0, 2, (3, 2))	$(3_u,3_\ell)$	$ g^{u\ell}_{\mathcal{Q}_1} ^2/M^2_{\mathcal{Q}_1}$	$\mathcal{O}_{\ell u}$	
$\mathcal{Q}_1 \sim (3, 2)_{rac{1}{6}}$	$(ar{3}_d,ar{3}_q)$	$2 g_{{\cal Q}_1}^{dq} ^2/(3M_{{\cal Q}_1}^2)$	${\cal O}_{qd}^{(1)} - 3 {\cal O}_{qd}^{(8)}$	
	$(3_d, 3_\ell)$	$ g_{O_{\rm F}}^{d\ell} ^2/M_{O_{\rm F}}^2$	$\mathcal{O}_{\ell d}$	
$\mathcal{Q}_5 \sim (3, 2)_{-rac{5}{c}}$	$(3_e,3_q)$	$ g_{\mathcal{O}_{5}}^{eq} ^{2}/M_{\mathcal{O}_{5}}^{2}$	\mathcal{O}_{qe}	
	$(ar{3}_u,ar{3}_q)$	$2 g_{\mathcal{Q}_5}^{uq} ^2/(3M_{\mathcal{Q}_5}^2)$	$\mathcal{O}_{qu}^{(1)}-3\mathcal{O}_{qu}^{(8)}$	
$\mathcal{X} \sim (3, 3)_{rac{2}{3}}$	$(ar{3}_\ell, 3_q)$	$-\left g_{\mathcal{X}} ight ^{2}/(8M_{\mathcal{X}}^{2})$	$3\mathcal{O}_{\ell q}^{(1)}-\mathcal{O}_{\ell q}^{(3)}$	
$\mathcal{Y}_1 \sim (ar{6}, 2)_{rac{1}{6}}$	$(ar{3}_d,ar{3}_q)$	$\left g_{\mathcal{Y}_{1}} ight ^{2}/(3M_{\mathcal{Y}_{1}}^{2})$	$2 {\cal O}_{qd}^{(1)} + 3 {\cal O}_{qd}^{(8)}$	
$\mathcal{Y}_5 \sim (ar{6}, 2)_{-rac{5}{6}}$	$(ar{3}_u,ar{3}_q)$	$\left g_{\mathcal{Y}_{5}} ight ^{2}/(3M_{\mathcal{Y}_{5}}^{2})$	$2 {\cal O}_{qu}^{(1)} + 3 {\cal O}_{qu}^{(8)}$	
	8_{a}	$-(g_{C}^{q})^{2}/(144M_{C}^{2})$	$11\mathcal{O}_{ag}^{(1)D} - 9\mathcal{O}_{ag}^{(1)E} + 9\mathcal{O}_{ag}^{(3)D} - 3\mathcal{O}_{ag}^{(3)E}$	
${\cal G} \sim ({f 8},{f 1})_0$	$8_{u}^{\mathbf{r}}$	$(g^u_G)^2/(36M^2_G)$	$3\mathcal{O}_{uu}^E - 5\mathcal{O}_{uu}^D$	
- (-)-)0	8_{d}	$(g^{d}_{\mathcal{G}})^{2}/(36M^{2}_{\mathcal{G}})$	$3\mathcal{O}_{dd}^{E}-5\mathcal{O}_{dd}^{D}$	
$\mathcal{G}_1 \sim (8, 1)_1$	$(ar{3}_d, 3_u)$	$\left g_{\mathcal{G}_{1}} ight ^{2}/(9M_{\mathcal{G}_{1}}^{2})$	$-4\mathcal{O}_{ud}^{(1)}+3\mathcal{O}_{ud}^{(8)}$	
$\mathcal{H} \sim (8, 3)_0$	8_q	$-(g_{\mathcal{H}})^2/(576M_{\mathcal{H}}^2)$	$27\mathcal{O}_{qq}^{(1)D} - 9\mathcal{O}_{qq}^{(1)E} - 7\mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(3)E}$	

Field	Irrep	Normalization	Operator
$N \sim (1, 1)_0$	3_ℓ	$ \lambda_N ^2/(4M_N^2)$	$\mathcal{O}_{\phi\ell}^{(1)}-\mathcal{O}_{\phi\ell}^{(3)}$
$E \sim (1, 1)_{-1}$	3_ℓ	$- \lambda_E ^2/(4M_E^2)$	$\mathcal{O}_{\phi\ell}^{(1)} + \mathcal{O}_{\phi\ell}^{(3)} - [2y_e^*\mathcal{O}_{e\phi} + ext{h.c.}]$
$\Delta_1 \sim (1, 2)_{-rac{1}{2}}$	3_{e}	$ \lambda_{\Delta_1} ^2/(2M_{\Delta_1}^2)$	$\mathcal{O}_{\phi e} + [y_e^*\mathcal{O}_{e\phi} + ext{h.c.}]$
$\Delta_3 \sim (1, 2)_{-rac{3}{2}}$	3_{e}	$- \lambda_{\Delta_3} ^2/(2M_{\Delta_3}^2)$	$\mathcal{O}_{\phi e} - [y_e^*\mathcal{O}_{e\phi} + ext{h.c.}]$
$\Sigma \sim ({f 1},{f 3})_0$	3_ℓ	$ \lambda_{\Sigma} ^2/(16M_{\Sigma}^2)$	$3 {\cal O}_{\phi\ell}^{(1)} + {\cal O}_{\phi\ell}^{(3)} + [4 y_e^* {\cal O}_{e\phi} + { m h.c.}]$
$\Sigma_1 \sim (1, 3)_{-1}$	3_ℓ	$ \lambda_{\Sigma_1} ^2/(16M_{\Sigma_1}^2)$	${\cal O}_{\phi\ell}^{(3)}-3{\cal O}_{\phi\ell}^{(1)}+[2y_e^*{\cal O}_{e\phi}+{ m h.c.}]$
$U \sim (3, 1)_{rac{2}{3}}$	3_q	$\left \lambda_U ight ^2/(4M_U^2)$	$\mathcal{O}_{\phi q}^{(1)} - \mathcal{O}_{\phi q}^{(3)} + [2y_u^*\mathcal{O}_{u\phi} + ext{h.c.}]$
$D \sim (3, 1)_{-\frac{1}{3}}$	3_q	$-\left \lambda_{D} ight ^{2}/(4M_{D}^{2})$	$\mathcal{O}_{\phi q}^{(1)} + \mathcal{O}_{\phi q}^{(3)} - [2y_d^*\mathcal{O}_{d\phi} + ext{h.c.}]$
(2.2)	3_{u}	$- \lambda^u_{Q_1} ^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi u} - [y^*_u \mathcal{O}_{u \phi} + ext{h.c.}]$
$Q_1 \sim (3, 2)_{rac{1}{6}}$	3_d	$ \lambda^d_{Q_1} ^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi d} + [y_d^*\mathcal{O}_{d\phi} + ext{h.c.}]$
$Q_5 \sim (3, 2)_{-rac{5}{6}}$	3_d	$- \lambda_{Q_5} ^2/(2M_{Q_5}^2)$	$\mathcal{O}_{\phi d} - [y_d^*\mathcal{O}_{d\phi} + ext{h.c.}]$
$Q_7 \sim ({f 3},{f 2})_{7\over 6}$	3_{u}	$ \lambda_{Q_7} ^2/(2M_{Q_7}^2)$	$\mathcal{O}_{\phi u} + [y^*_u \mathcal{O}_{u \phi} + ext{h.c.}]$
$T_1 \sim (3, 3)_{-\frac{1}{3}}$	3_q	$ \lambda_{T_1} ^2/(16M_{T_1}^2)$	$\mathcal{O}_{\phi q}^{(3)} - 3\mathcal{O}_{\phi q}^{(1)} + [2y_d^*\mathcal{O}_{d\phi} + 4y_u^*\mathcal{O}_{u\phi} + \mathrm{h.c.}]$
$T_2 \sim (3, 3)_{\frac{2}{3}}$	3_q	$ \lambda_{T_2} ^2/(16M_{T_2}^2)$	$\mathcal{O}_{\phi q}^{(3)}+3\mathcal{O}_{\phi q}^{(1)}+[4y_d^*\mathcal{O}_{d\phi}+2y_u^*\mathcal{O}_{u\phi}+ ext{h.c.}]$







Leading directions: Results

Field	Irrep	Normalization	Operator
$\mathcal{S}_1 \sim (1, 1)_1$	3_ℓ	$ y_{\mathcal{S}_1} ^2/M_{\mathcal{S}_1}^2$	$\mathcal{O}^{D}_{\ell\ell}-\mathcal{O}^{E}_{\ell\ell}$
$\mathcal{S}_2 \sim (1, 1)_2$	$ar{6}_{e}$	$ y_{\mathcal{S}_2} ^2/(2M_{\mathcal{S}_2}^2)$	\mathcal{O}_{ee}
	$(ar{3}_e, 3_\ell)$	$- y^e_arphi ^2/(2M^2_arphi)$	$\mathcal{O}_{\ell e}$
$arphi \sim (1,2)_{rac{1}{2}}$	$(ar{3}_d, 3_q)$	$- y^d_arphi ^2/(6M^2_arphi)$	${\cal O}_{qd}^{(1)}+6{\cal O}_{qd}^{(8)}$
	$(ar{3}_q, 3_u)$	$- y^u_arphi ^2/(6M^2_arphi)$	$\mathcal{O}_{qu}^{(1)}+6\mathcal{O}_{qu}^{(8)}$
$\Xi_1 \sim (1, 3)_1$	$ar{6}_\ell$	$ y_{\Xi_1} ^2 /(2M_{\Xi_1}^2)$	$\mathcal{O}^{D}_{\ell\ell} + \mathcal{O}^{E}_{\ell\ell}$
	$({f 3}_q,{f 3}_\ell)$	$ y^{q\ell}_{\omega_1} ^2/(4M^2_{\omega_1})$	$\mathcal{O}_{\ell q}^{(1)} - \mathcal{O}_{\ell q}^{(3)}$
(9.1)	$(3_e,3_u)$	$ y^{eu}_{\omega_1} ^2/(2M^2_{\omega_1})$	\mathcal{O}_{eu}
$\omega_1 \sim (3, 1)_{-\frac{1}{3}}$	$ar{6}_q$	$ y^{qq}_{\omega_1} ^2/(4M^2_{\omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} + \mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$
	$(ar{3}_d,ar{3}_u)$	$ y^{du}_{\omega_1} ^2/(3M^2_{\omega_1})$	${\cal O}_{ud}^{(1)} - 3 {\cal O}_{ud}^{(8)}$
$\omega_2 \sim (3, 1)_{rac{2}{3}}$	3_d	$ y_{\omega_2} ^2/M_{\omega_2}^2$	$\mathcal{O}^{D}_{dd} - \mathcal{O}^{E}_{dd}$
(0,1)	$(3_e,3_d)$	$ y^{ed}_{\omega_4} ^2/(2M^2_{\omega_4})$	\mathcal{O}_{ed}
$\omega_4 \sim (3, 1)_{-\frac{4}{3}}$	3_{u}	$ y^{uu}_{\omega_4} ^2/M^2_{\omega_4}$	$\mathcal{O}^{D}_{uu}-\mathcal{O}^{E}_{uu}$
$\Pi_1 \sim ({f 3},{f 2})_{rac{1}{6}}$	$(ar{3}_\ell, 3_d)$	$- y_{\Pi_1} ^2/(2M_{\Pi_1}^2)$	$\mathcal{O}_{\ell d}$
$\Pi_{\mathbf{z}} \sim (3, 2)_{\mathbf{z}}$	$(ar{3}_\ell, 3_u)$	$-\left y_{\Pi_7}^{\ell u} ight ^2/(2M_{\Pi_7}^2)$	$\mathcal{O}_{\ell u}$
$\Pi_7 \sim (3, 2)_{\frac{7}{6}}$	$(ar{3}_e, 3_q)$	$- y_{\Pi_7}^{qe} ^2/(2M_{\Pi_7}^2)$	\mathcal{O}_{qe}
(3 , 3)	$({f 3}_q,{f 3}_\ell)$	$ y_{\zeta}^{q\ell} ^2/(4M_{\zeta}^2)$	$3\mathcal{O}_{\ell q}^{(1)}+\mathcal{O}_{\ell q}^{(3)}$
$\zeta = (0, 0)_{-\frac{1}{3}}$	3_{q}	$ y_\zeta^{qq} ^2/(2M_\zeta^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$
O_{1}	$(3_u,3_d)$	$ y^{ud}_{\Omega_1} ^2/(6M^2_{\Omega_1})$	$2 {\cal O}_{ud}^{(1)} + 3 {\cal O}_{ud}^{(8)}$
$\Omega_1 \sim (0, 1)_{\frac{1}{3}}$	$ar{3}_q$	$ y^{qq}_{\Omega_1} ^2/(4M^2_{\Omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} - \mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$
$\Omega_2 \sim (6, 1)_{-rac{2}{3}}$	6_d	$ y_{\Omega_2} ^2/(4M_{\Omega_2}^2)$	$\mathcal{O}^{D}_{dd} + \mathcal{O}^{E}_{dd}$
$\Omega_4 \sim ({f 6},{f 1})_{4\over 3}$	6_{u}	$ y_{\Omega_4} ^2/(4M_{\Omega_4}^2)$	$\mathcal{O}^{D}_{uu} + \mathcal{O}^{E}_{uu}$
$\Upsilon \sim ({f 6},{f 3})_{1\over 3}$	6_q	$ y_\Upsilon ^2/(8M_\Upsilon^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} + 3\mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$
Φ (9 0)	$(ar{3}_q, 3_u)$	$- y^{qu}_{\Phi} ^2/(18M_{\Phi}^2)$	$4 {\cal O}_{qu}^{(1)} - 3 {\cal O}_{qu}^{(8)}$
$\Psi \sim (\mathbf{\delta}, \mathbf{Z})_{rac{1}{2}}$	$(ar{3}_d, 3_q)$	$- y_{\Phi}^{dq} ^2/(18 M_{\Phi}^2)$	$4 {\cal O}_{qd}^{(1)} - 3 {\cal O}_{qd}^{(8)}$

Field	Irrep	Normalization	Operator
${\cal B} \sim ({f 1},{f 1})_0$	$egin{array}{ccc} {f 8}_\ell \ {f 8}_e \ {f 8}_q \ {f 8}_u \ {f 8}_u \end{array}$	$-(g_{\mathcal{B}}^{\ell})^2/(12M_{\mathcal{B}}^2) \ -(g_{\mathcal{B}}^e)^2/(6M_{\mathcal{B}}^2) \ -(g_{\mathcal{B}}^q)^2/(12M_{\mathcal{B}}^2) \ -(g_{\mathcal{B}}^u)^2/(12M_{\mathcal{B}}^2)$	$egin{aligned} & 3\mathcal{O}^E_{\ell\ell} - \mathcal{O}^D_{\ell\ell} \ & \mathcal{O}_{ee} \ & 3\mathcal{O}^{(1)E}_{qq} - \mathcal{O}^{(1)D}_{qq} \ & 3\mathcal{O}^E_{uu} - \mathcal{O}^D_{uu} \end{aligned}$
	8 _d	$-(g_{\mathcal{B}}^d)^2/(12M_{\mathcal{B}}^2)$	$\frac{3\mathcal{O}_{dd}^E - \mathcal{O}_{dd}^D}{\sigma^{(1)} + \sigma^{(8)}}$
$\mathcal{B}_1 \sim (1, 1)_1$	$(3_d, 3_u)$	$- g^{aa}_{{\cal B}_1} ^2/(3M^2_{{\cal B}_1})$	$\mathcal{O}_{ud}^{(2)} + 6\mathcal{O}_{ud}^{(2)}$
$\mathcal{W} \sim (1, 3)_0$	$\frac{8_q}{8_\ell}$	$-(g^q_{\mathcal{W}})^2/(48M^2_{\mathcal{W}})\ (g^\ell_{\mathcal{W}})^2/(48M^2_{\mathcal{W}})$	$egin{aligned} & 3\mathcal{O}_{qq}^{(3)E} - \mathcal{O}_{qq}^{(3)D} \ & 5\mathcal{O}_{\ell\ell}^E - 7\mathcal{O}_{\ell\ell}^D \end{aligned}$
$\mathcal{L}_3 \sim (1, 2)_{-rac{3}{2}}$	$(3_e,3_\ell)$	$\left g_{\mathcal{L}_3} ight ^2/M_{\mathcal{L}_3}^2$	$\mathcal{O}_{\ell e}$
$\mathcal{U}_2 \sim (3, 1)_{rac{2}{3}}$	$egin{aligned} & (ar{3}_e, 3_d) \ & (ar{3}_\ell, 3_q) \end{aligned}$	$- g^{ed}_{\mathcal{U}_2} ^2/M^2_{\mathcal{U}_2} \ - g^{\ell q}_{\mathcal{U}_2} ^2/(2M^2_{\mathcal{U}_2})$	$\mathcal{O}_{ed} \ \mathcal{O}_{\ell q}^{(1)} + \mathcal{O}_{\ell q}^{(3)}$
$\mathcal{U}_5 \sim (3, 1)_{rac{5}{3}}$	$(ar{3}_e, 3_u)$	$- g_{\mathcal{U}_5} ^2/M_{\mathcal{U}_5}^2$	\mathcal{O}_{eu}
$\mathcal{Q}_1 \sim (3, 2)_{rac{1}{6}}$	$egin{aligned} (3_u, 3_\ell) \ (ar{3}_d, ar{3}_q) \end{aligned}$	$ g^{u\ell}_{\mathcal{Q}_1} ^2/M^2_{\mathcal{Q}_1} \ 2 g^{dq}_{\mathcal{Q}_1} ^2/(3M^2_{\mathcal{Q}_1})$	$\mathcal{O}_{\ell u} \ \mathcal{O}_{qd}^{(1)} - 3\mathcal{O}_{qd}^{(8)}$
$\mathcal{Q}_5 \sim (3, 2)_{-rac{5}{6}}$	$egin{aligned} & (3_d, 3_\ell) \ & (3_e, 3_q) \ & (ar{3}_u, ar{3}_q) \end{aligned}$	$ g_{\mathcal{Q}_5}^{d\ell} ^2/M_{\mathcal{Q}_5}^2 \ g_{\mathcal{Q}_5}^{eq} ^2/M_{\mathcal{Q}_5}^2 \ 2 g_{\mathcal{Q}_5}^{uq} ^2/(3M_{\mathcal{Q}_5}^2)$	$\mathcal{O}_{\ell d} \ \mathcal{O}_{q e} \ \mathcal{O}_{q u}^{(1)} - 3 \mathcal{O}_{q u}^{(8)}$
$\mathcal{X} \sim (3, 3)_{rac{2}{3}}$	$(ar{3}_\ell, 3_q)$	$-\left g_{\mathcal{X}} ight ^{2}/(8M_{\mathcal{X}}^{2})$	$3\mathcal{O}_{\ell q}^{(1)}-\mathcal{O}_{\ell q}^{(3)}$
$\mathcal{Y}_1 \sim (ar{6}, 2)_{rac{1}{6}}$	$(ar{3}_d,ar{3}_q)$	$\left g_{\mathcal{Y}_{1}} ight ^{2}/(3M_{\mathcal{Y}_{1}}^{2})$	$2 {\cal O}_{qd}^{(1)} + 3 {\cal O}_{qd}^{(8)}$
$\mathcal{Y}_5 \sim (ar{6}, 2)_{-rac{5}{6}}$	$(ar{3}_u,ar{3}_q)$	$\left g_{\mathcal{Y}_{5}} ight ^{2}/(3M_{\mathcal{Y}_{5}}^{2})$	$2\mathcal{O}_{qu}^{(1)} + 3\mathcal{O}_{qu}^{(8)}$
${\cal G} \sim ({f 8},{f 1})_0$	$egin{array}{c} {f 8}_q \ {f 8}_u \ {f 8}_d \end{array}$	$-(g^q_{\mathcal{G}})^2/(144M^2_{\mathcal{G}}) \ (g^u_{\mathcal{G}})^2/(36M^2_{\mathcal{G}}) \ (g^d_{\mathcal{G}})^2/(36M^2_{\mathcal{G}})$	$\begin{array}{c} 11\mathcal{O}_{qq}^{(1)D} - 9\mathcal{O}_{qq}^{(1)E} + 9\mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(3)E} \\ 3\mathcal{O}_{uu}^E - 5\mathcal{O}_{uu}^D \\ 3\mathcal{O}_{dd}^E - 5\mathcal{O}_{dd}^D \end{array}$
$\mathcal{G}_1 \sim (8, 1)_1$	$(ar{3}_d, 3_u)$	$\left g_{\mathcal{G}_{1}} ight ^{2}/(9M_{\mathcal{G}_{1}}^{2})$	$-4 {\cal O}_{ud}^{(1)} + 3 {\cal O}_{ud}^{(8)}$
$\mathcal{H} \sim (8, 3)_0$	8_q	$-(g_{\mathcal{H}})^2/(576M_{\mathcal{H}}^2)$	$27\mathcal{O}_{qq}^{(1)D} - 9\mathcal{O}_{qq}^{(1)E} - 7\mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(3)E}$

Field	Irrep	Normalization	Operator
$N \sim (1, 1)_0$	3_ℓ	$ \lambda_N ^2/(4M_N^2)$	$\mathcal{O}_{\phi\ell}^{(1)}-\mathcal{O}_{\phi\ell}^{(3)}$
$E \sim (1, 1)_{-1}$	3_ℓ	$- \lambda_E ^2/(4M_E^2)$	$\mathcal{O}_{\phi\ell}^{(1)}+\mathcal{O}_{\phi\ell}^{(3)}-[2y_e^*\mathcal{O}_{e\phi}+ ext{h.c.}]$
$\Delta_1 \sim (1, 2)_{-rac{1}{2}}$	3_{e}	$ \lambda_{\Delta_1} ^2/(2M_{\Delta_1}^2)$	$\mathcal{O}_{\phi e} + [y_e^*\mathcal{O}_{e\phi} + ext{h.c.}]$
$\Delta_3 \sim (1, 2)_{-rac{3}{2}}$	3_{e}	$- \lambda_{\Delta_3} ^2/(2M_{\Delta_3}^2)$	$\mathcal{O}_{\phi e} - [y_e^*\mathcal{O}_{e\phi} + ext{h.c.}]$
$\Sigma \sim ({f 1},{f 3})_0$	3_ℓ	$ \lambda_{\Sigma} ^2/(16M_{\Sigma}^2)$	$3\mathcal{O}_{\phi\ell}^{(1)} + \mathcal{O}_{\phi\ell}^{(3)} + [4y_e^*\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Sigma_1 \sim (1, 3)_{-1}$	3_ℓ	$ \lambda_{\Sigma_1} ^2/(16M_{\Sigma_1}^2)$	${\cal O}_{\phi\ell}^{(3)} - 3{\cal O}_{\phi\ell}^{(1)} + [2y_e^*{\cal O}_{e\phi} + { m h.c.}]$
$U \sim (3, 1)_{rac{2}{3}}$	3_q	$\left \lambda_U ight ^2/(4M_U^2)$	$\mathcal{O}_{\phi q}^{(1)} - \mathcal{O}_{\phi q}^{(3)} + [2y_u^*\mathcal{O}_{u\phi} + ext{h.c.}]$
$D \sim (3, 1)_{-\frac{1}{3}}$	3_q	$-\left \lambda_{D} ight ^{2}/(4M_{D}^{2})$	$\mathcal{O}_{\phi q}^{(1)} + \mathcal{O}_{\phi q}^{(3)} - [2y_d^*\mathcal{O}_{d\phi} + \mathrm{h.c.}]$
(2, 2)	3_{u}	$- \lambda^u_{Q_1} ^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi u} - [y^*_u \mathcal{O}_{u \phi} + ext{h.c.}]$
$Q_1 \sim (3, 2)_{rac{1}{6}}$	3_d	$ \lambda^d_{Q_1} ^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi d} + [y_d^*\mathcal{O}_{d\phi} + ext{h.c.}]$
$Q_5 \sim (3, 2)_{-rac{5}{6}}$	3_d	$- \lambda_{Q_5} ^2/(2M_{Q_5}^2)$	$\mathcal{O}_{\phi d} - [y_d^*\mathcal{O}_{d\phi} + ext{h.c.}]$
$Q_7 \sim ({f 3},{f 2})_{7\over 6}$	3_{u}	$ \lambda_{Q_7} ^2/(2M_{Q_7}^2)$	$\mathcal{O}_{\phi u} + [y^*_u \mathcal{O}_{u \phi} + ext{h.c.}]$
$T_1 \sim (3, 3)_{-\frac{1}{3}}$	3_q	$ \lambda_{T_1} ^2/(16M_{T_1}^2)$	$\mathcal{O}_{\phi q}^{(3)} - 3\mathcal{O}_{\phi q}^{(1)} + [2y_d^*\mathcal{O}_{d\phi} + 4y_u^*\mathcal{O}_{u\phi} + \text{h.c.}]$
$T_2 \sim (3, 3)_{rac{2}{3}}$	3_q	$ \lambda_{T_2} ^2/(16M_{T_2}^2)$	$\mathcal{O}_{\phi q}^{(3)} + 3\mathcal{O}_{\phi q}^{(1)} + [4y_d^*\mathcal{O}_{d\phi} + 2y_u^*\mathcal{O}_{u\phi} + \text{h.c.}]$

Most of cases integrate out to a lacksquaresingle linear combination of operators in the MFV basis.









Leading directions: Results

Field	Irrep	Normalization	Operator
$\mathcal{S}_1 \sim (1, 1)_1$	3_ℓ	$ y_{\mathcal{S}_1} ^2/M_{\mathcal{S}_1}^2$	$\mathcal{O}^{D}_{\ell\ell}-\mathcal{O}^{E}_{\ell\ell}$
$\mathcal{S}_2 \sim (1, 1)_2$	$ar{6}_{e}$	$ y_{\mathcal{S}_2} ^2/(2M_{\mathcal{S}_2}^2)$	\mathcal{O}_{ee}
	$(ar{3}_e, 3_\ell)$	$- y^e_arphi ^2/(2M^2_arphi)$	$\mathcal{O}_{\ell e}$
$arphi \sim (1,2)_{rac{1}{2}}$	$(ar{3}_d, 3_q)$	$- y^d_arphi ^2/(6M^2_arphi)$	${\cal O}_{qd}^{(1)}+6{\cal O}_{qd}^{(8)}$
	$(ar{3}_q, 3_u)$	$- y^u_arphi ^2/(6M^2_arphi)$	$\mathcal{O}_{qu}^{(1)}+6\mathcal{O}_{qu}^{(8)}$
$\Xi_1 \sim (1, 3)_1$	$ar{6}_\ell$	$ y_{\Xi_1} ^2 /(2M_{\Xi_1}^2)$	$\mathcal{O}^{D}_{\ell\ell} + \mathcal{O}^{E}_{\ell\ell}$
	$(3_q,3_\ell)$	$ y^{q\ell}_{\omega_1} ^2/(4M^2_{\omega_1})$	$\mathcal{O}_{\ell q}^{(1)} - \mathcal{O}_{\ell q}^{(3)}$
(9.1)	$(3_e,3_u)$	$ y^{eu}_{\omega_1} ^2/(2M^2_{\omega_1})$	\mathcal{O}_{eu}
$\omega_1 \sim (3, 1)_{-\frac{1}{3}}$	$ar{6}_q$	$ y^{qq}_{\omega_1} ^2/(4M^2_{\omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} + \mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$
	$(ar{3}_d,ar{3}_u)$	$ y^{du}_{\omega_1} ^2/(3M^2_{\omega_1})$	${\cal O}_{ud}^{(1)} - 3 {\cal O}_{ud}^{(8)}$
$\omega_2 \sim (3, 1)_{rac{2}{3}}$	3_d	$ y_{\omega_2} ^2/M_{\omega_2}^2$	$\mathcal{O}^{D}_{dd} - \mathcal{O}^{E}_{dd}$
(0,1)	$(3_e,3_d)$	$ y^{ed}_{\omega_4} ^2/(2M^2_{\omega_4})$	\mathcal{O}_{ed}
$\omega_4 \sim (3, 1)_{-\frac{4}{3}}$	3_{u}	$ y^{uu}_{\omega_4} ^2/M^2_{\omega_4}$	$\mathcal{O}^{D}_{uu}-\mathcal{O}^{E}_{uu}$
$\Pi_1 \sim ({f 3},{f 2})_{rac{1}{6}}$	$(ar{3}_\ell, 3_d)$	$- y_{\Pi_1} ^2/(2M_{\Pi_1}^2)$	$\mathcal{O}_{\ell d}$
$\Pi_{\mathbf{z}} \sim (3, 2)_{\mathbf{z}}$	$(ar{3}_\ell, 3_u)$	$-\left y_{\Pi_7}^{\ell u} ight ^2/(2M_{\Pi_7}^2)$	$\mathcal{O}_{\ell u}$
$\Pi_7 \sim (3, 2)_{rac{7}{6}}$	$(ar{3}_e, 3_q)$	$- y_{\Pi_7}^{qe} ^2/(2M_{\Pi_7}^2)$	\mathcal{O}_{qe}
(3 , 3)	$(3_q,3_\ell)$	$ y_{\zeta}^{q\ell} ^2/(4M_{\zeta}^2)$	$3\mathcal{O}_{\ell q}^{(1)}+\mathcal{O}_{\ell q}^{(3)}$
$\zeta = (0, 0)_{-\frac{1}{3}}$	3_q	$ y_\zeta^{qq} ^2/(2M_\zeta^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$
O_{1}	$(3_u,3_d)$	$ y^{ud}_{\Omega_1} ^2/(6M^2_{\Omega_1})$	$2 {\cal O}_{ud}^{(1)} + 3 {\cal O}_{ud}^{(8)}$
$\Omega_1 \sim (0, 1)_{\frac{1}{3}}$	$ar{3}_q$	$ y^{qq}_{\Omega_1} ^2/(4M^2_{\Omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} - \mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$
$\Omega_2 \sim (6, 1)_{-rac{2}{3}}$	6_d	$ y_{\Omega_2} ^2/(4M_{\Omega_2}^2)$	$\mathcal{O}^{D}_{dd} + \mathcal{O}^{E}_{dd}$
$\Omega_4 \sim ({f 6},{f 1})_{4\over 3}$	6_{u}	$ y_{\Omega_4} ^2/(4M_{\Omega_4}^2)$	$\mathcal{O}^{D}_{uu} + \mathcal{O}^{E}_{uu}$
$\Upsilon \sim ({f 6},{f 3})_{1\over 3}$	6_q	$ y_\Upsilon ^2/(8M_\Upsilon^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} + 3\mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$
Φ (9 0)	$(ar{3}_q, 3_u)$	$- y^{qu}_{\Phi} ^2/(18M_{\Phi}^2)$	$4 {\cal O}_{qu}^{(1)} - 3 {\cal O}_{qu}^{(8)}$
$\Psi \sim (\mathbf{\delta}, \mathbf{Z})_{rac{1}{2}}$	$(ar{3}_d, 3_q)$	$- y_{\Phi}^{dq} ^2/(18 M_{\Phi}^2)$	$4 {\cal O}_{qd}^{(1)} - 3 {\cal O}_{qd}^{(8)}$

Field	Irrep	Normalization	Operator
	$egin{array}{c} {f 8}_\ell \ {f 8}_e \end{array}$	$-(g^\ell_{\mathcal{B}})^2/(12M^2_{\mathcal{B}}) \ -(g^e_{\mathcal{B}})^2/(6M^2_{\mathcal{B}})$	$3\mathcal{O}^E_{\ell\ell}-\mathcal{O}^D_{\ell\ell}\ \mathcal{O}_{ee}$
$\mathcal{B} \sim (1, 1)_0$	$egin{array}{c} {f 8}_q \ {f 8}_u \ {f 8}_d \end{array}$	$egin{aligned} -(g^q_{\mathcal{B}})^2/(12M^2_{\mathcal{B}}) \ -(g^u_{\mathcal{B}})^2/(12M^2_{\mathcal{B}}) \ -(g^d_{\mathcal{B}})^2/(12M^2_{\mathcal{B}}) \end{aligned}$	$egin{aligned} & 3\mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(1)D} \ & 3\mathcal{O}_{uu}^E - \mathcal{O}_{uu}^D \ & 3\mathcal{O}_{dd}^E - \mathcal{O}_{dd}^D \end{aligned}$
$\mathcal{B}_1 \sim (1, 1)_1$	$(ar{3}_d, 3_u)$	$- g^{du}_{{\cal B}_1} ^2/(3M^2_{{\cal B}_1})$	$\mathcal{O}_{ud}^{(1)} + 6\mathcal{O}_{ud}^{(8)}$
$\mathcal{W} \sim (1, 3)_0$	$egin{array}{c} {f 8}_q \ {f 8}_\ell \end{array}$	$-(g^q_{\mathcal{W}})^2/(48M^2_{\mathcal{W}})\ (g^\ell_{\mathcal{W}})^2/(48M^2_{\mathcal{W}})$	$egin{aligned} & 3\mathcal{O}_{qq}^{(3)E} - \mathcal{O}_{qq}^{(3)D} \ & 5\mathcal{O}_{\ell\ell}^E - 7\mathcal{O}_{\ell\ell}^D \end{aligned}$
$\mathcal{L}_3 \sim (1, 2)_{-rac{3}{2}}$	$(3_e,3_\ell)$	$\left g_{\mathcal{L}_3} ight ^2/M_{\mathcal{L}_3}^2$	$\mathcal{O}_{\ell e}$
$\mathcal{U}_2 \sim (3, 1)_{rac{2}{3}}$	$egin{aligned} & (ar{3}_e, 3_d) \ & (ar{3}_\ell, 3_q) \end{aligned}$	$- g^{ed}_{\mathcal{U}_2} ^2/M^2_{\mathcal{U}_2} onumber \ - g^{\ell q}_{\mathcal{U}_2} ^2/(2M^2_{\mathcal{U}_2})$	$\mathcal{O}_{ed} \ \mathcal{O}_{\ell q}^{(1)} + \mathcal{O}_{\ell q}^{(3)}$
$\mathcal{U}_5 \sim (3, 1)_{rac{5}{3}}$	$(ar{3}_e, 3_u)$	$- g_{\mathcal{U}_5} ^2/M_{\mathcal{U}_5}^2$	\mathcal{O}_{eu}
$\mathcal{Q}_1 \sim (3, 2)_{rac{1}{6}}$	$egin{aligned} (3_u,3_\ell)\ (ar{3}_d,ar{3}_q) \end{aligned}$	$ g^{u\ell}_{\mathcal{Q}_1} ^2/M^2_{\mathcal{Q}_1} \ 2 g^{dq}_{\mathcal{Q}_1} ^2/(3M^2_{\mathcal{Q}_1})$	$\mathcal{O}_{\ell u} \ \mathcal{O}_{qd}^{(1)} - 3\mathcal{O}_{qd}^{(8)}$
$\mathcal{Q}_5 \sim (3, 2)_{-rac{5}{6}}$	$egin{aligned} ({f 3}_d,{f 3}_\ell) \ ({f 3}_e,{f 3}_q) \ (ar {f 3}_u,ar {f 3}_q) \end{aligned}$	$ g_{\mathcal{Q}_5}^{d\ell} ^2/M_{\mathcal{Q}_5}^2 \ g_{\mathcal{Q}_5}^{eq} ^2/M_{\mathcal{Q}_5}^2 \ 2 g_{\mathcal{Q}_5}^{uq} ^2/(3M_{\mathcal{Q}_5}^2)$	$\mathcal{O}_{\ell d} \ \mathcal{O}_{q e} \ \mathcal{O}_{q u}^{(1)} - 3 \mathcal{O}_{q u}^{(8)}$
$\mathcal{X} \sim (3,3)_{rac{2}{3}}$	$(ar{3}_\ell, 3_q)$	$-\left g_{\mathcal{X}} ight ^{2}/(8M_{\mathcal{X}}^{2})$	$3\mathcal{O}_{\ell q}^{(1)}-\mathcal{O}_{\ell q}^{(3)}$
$\mathcal{Y}_1 \sim (ar{6}, 2)_{rac{1}{6}}$	$(ar{3}_d,ar{3}_q)$	$\left g_{\mathcal{Y}_{1}} ight ^{2}/(3M_{\mathcal{Y}_{1}}^{2})$	$2\mathcal{O}_{qd}^{(1)} + 3\mathcal{O}_{qd}^{(8)}$
$\mathcal{Y}_5 \sim (ar{6}, 2)_{-rac{5}{6}}$	$(ar{3}_u,ar{3}_q)$	$\left g_{\mathcal{Y}_{5}} ight ^{2}/(3M_{\mathcal{Y}_{5}}^{2})$	$2\mathcal{O}_{qu}^{(1)} + 3\mathcal{O}_{qu}^{(8)}$
${\cal G} \sim ({f 8},{f 1})_0$	$egin{array}{c} {f 8}_q \ {f 8}_u \ {f 8}_d \end{array}$	$-(g^q_{\mathcal{G}})^2/(144M^2_{\mathcal{G}}) \ (g^u_{\mathcal{G}})^2/(36M^2_{\mathcal{G}}) \ (g^d_{\mathcal{G}})^2/(36M^2_{\mathcal{G}})$	$\begin{array}{c} 11\mathcal{O}_{qq}^{(1)D} - 9\mathcal{O}_{qq}^{(1)E} + 9\mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(3)E} \\ 3\mathcal{O}_{uu}^E - 5\mathcal{O}_{uu}^D \\ 3\mathcal{O}_{dd}^E - 5\mathcal{O}_{dd}^D \end{array}$
$\mathcal{G}_1 \sim (8, 1)_1$	$(ar{3}_d, 3_u)$	$\left g_{\mathcal{G}_{1}} ight ^{2}/(9M_{\mathcal{G}_{1}}^{2})$	$-4 {\cal O}^{(1)}_{ud} + 3 {\cal O}^{(8)}_{ud}$
$\mathcal{H} \sim (8, 3)_0$	8_q	$-(g_{\mathcal{H}})^2/(576M_{\mathcal{H}}^2)$	$27\mathcal{O}_{qq}^{(1)D} - 9\mathcal{O}_{qq}^{(1)E} - 7\mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(3)E}$

Field	Irrep	Normalization	Operator
$N \sim (1, 1)_0$	3_ℓ	$ \lambda_N ^2/(4M_N^2)$	$\mathcal{O}_{\phi\ell}^{(1)}-\mathcal{O}_{\phi\ell}^{(3)}$
$E \sim (1, 1)_{-1}$	3_ℓ	$- \lambda_E ^2/(4M_E^2)$	$\mathcal{O}_{\phi\ell}^{(1)}+\mathcal{O}_{\phi\ell}^{(3)}-[2y_e^*\mathcal{O}_{e\phi}+ ext{h.c.}]$
$\Delta_1 \sim (1, 2)_{-rac{1}{2}}$	3_{e}	$ \lambda_{\Delta_1} ^2/(2M_{\Delta_1}^2)$	$\mathcal{O}_{\phi e} + [y_e^*\mathcal{O}_{e\phi} + ext{h.c.}]$
$\Delta_3 \sim (1, 2)_{-rac{3}{2}}$	3_{e}	$- \lambda_{\Delta_3} ^2/(2M_{\Delta_3}^2)$	$\mathcal{O}_{\phi e} - [y_e^*\mathcal{O}_{e\phi} + ext{h.c.}]$
$\Sigma \sim ({f 1},{f 3})_0$	3_ℓ	$ \lambda_{\Sigma} ^2/(16M_{\Sigma}^2)$	$3\mathcal{O}_{\phi\ell}^{(1)} + \mathcal{O}_{\phi\ell}^{(3)} + [4y_e^*\mathcal{O}_{e\phi} + \mathrm{h.c.}]$
$\Sigma_1 \sim (1, 3)_{-1}$	3_ℓ	$ \lambda_{\Sigma_1} ^2/(16M_{\Sigma_1}^2)$	$\mathcal{O}_{\phi\ell}^{(3)} - 3\mathcal{O}_{\phi\ell}^{(1)} + [2y_e^*\mathcal{O}_{e\phi} + ext{h.c.}]$
$U \sim (3, 1)_{\frac{2}{3}}$	3_q	$\left \lambda_U ight ^2/(4M_U^2)$	$\mathcal{O}_{\phi q}^{(1)} - \mathcal{O}_{\phi q}^{(3)} + [2y_u^*\mathcal{O}_{u\phi} + ext{h.c.}]$
$D \sim (3, 1)_{-\frac{1}{3}}$	3_q	$-\left \lambda_{D} ight ^{2}/(4M_{D}^{2})$	$\mathcal{O}_{\phi q}^{(1)}+\mathcal{O}_{\phi q}^{(3)}-[2y_d^*\mathcal{O}_{d\phi}+ ext{h.c.}]$
(\mathbf{p}, \mathbf{p})	3_{u}	$- \lambda^u_{Q_1} ^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi u} - [y^*_u \mathcal{O}_{u \phi} + ext{h.c.}]$
$Q_1 \sim (3, 2)_{rac{1}{6}}$	3_d	$ \lambda^d_{Q_1} ^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi d} + [y_d^*\mathcal{O}_{d\phi} + ext{h.c.}]$
$Q_5 \sim ({f 3},{f 2})_{-rac{5}{6}}$	3_d	$- \lambda_{Q_5} ^2/(2M_{Q_5}^2)$	$\mathcal{O}_{\phi d} - [y_d^*\mathcal{O}_{d\phi} + ext{h.c.}]$
$Q_7 \sim ({f 3},{f 2})_{7\over 6}$	3_{u}	$ \lambda_{Q_7} ^2/(2M_{Q_7}^2)$	$\mathcal{O}_{\phi u} + [y^*_u \mathcal{O}_{u \phi} + ext{h.c.}]$
$T_1 \sim (3, 3)_{-\frac{1}{3}}$	3_q	$ \lambda_{T_1} ^2/(16M_{T_1}^2)$	$\mathcal{O}_{\phi q}^{(3)} - 3\mathcal{O}_{\phi q}^{(1)} + [2y_d^*\mathcal{O}_{d\phi} + 4y_u^*\mathcal{O}_{u\phi} + \mathrm{h.c.}]$
$T_2 \sim ({\bf 3},{\bf 3})_{rac{2}{3}}$	3_q	$ \lambda_{T_2} ^2/(16M_{T_2}^2)$	$\mathcal{O}_{\phi q}^{(3)}+3\mathcal{O}_{\phi q}^{(1)}+[4y_d^*\mathcal{O}_{d\phi}+2y_u^*\mathcal{O}_{u\phi}+ ext{h.c.}]$

- Most of cases integrate out to a single linear combination of operators in the MFV basis.
- Leading directions suitable for 1D pheno analysis







- Compilation of the EFT bounds
- Phenomenological classes
 - Class I: 4-lepton
 - Class II: 2-quark-2-lepton
 - Class III: 4-quark
 - Class IV: W/Z corrections
 - Class V: oblique/Higgs







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 - Class V: oblique/Higgs

$\Xi_1 \sim \bar{6}_\ell$		
$\mathcal{S}_1 \sim 3_\ell$		
$\mathcal{W} \sim 8_{\ell}$		
$\mathcal{B} \sim 8_{\ell}$		
$\mathcal{L}_3 \sim (3_\ell, 3_e)$		
$\varphi \sim (\mathfrak{s}_{\ell}, \mathfrak{s}_{e})$ $\mathcal{S}_{2} \sim \overline{\mathfrak{6}}_{e}$		
$\mathcal{B} \sim 8_e$		
1	10	[TeV]





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$\mathcal{U}_2 \sim (3_q, \bar{3}_\ell)$		
$\mathcal{U}_5 \sim (3_u, \bar{3}_e)$		
$\omega_1 \sim (3_q, 3_\ell)$		
$\mathcal{X} \sim (3_q, \bar{3}_\ell)$		
$\mathcal{Q}_5 \sim (3_q, 3_e)$		
$\omega_1 \sim (3_u, 3_e)$		
$\mathcal{Q}_1 \sim (3_u, 3_\ell)$		
$\Pi_7 \sim (3_u, \bar{3}_\ell)$		
$\Pi_7 \sim (3_q, \bar{3}_e)$		
$\mathcal{U}_2 \sim (3_d, \bar{3}_e)$		
$\zeta \sim (3_q, 3_\ell)$		
$\omega_4 \sim (3_d, 3_e)$		
$\mathcal{Q}_5 \sim (3_d, 3_\ell)$		
$\Pi_1 \sim (3_d, \bar{3}_\ell)$		[Te\/]
	10	







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- Compilation of the EFT bounds
- Phenomenological classes
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Q_1
Q_7
Q_5









- Compilation of the EFT bounds •
- Phenomenological classes
 - Class I: 4-lepton
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 - Class III: 4-quark
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Tree-level EFT bounds



- Compilation of the EFT bounds
- Phenomenological classes
 - Class I: 4-lepton
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 - Class III: 4-quark
 - Class IV: W/Z corrections
 - Class V: oblique/Higgs



What about RG effects and for which directions are RG effects important?





- Compilation of the EFT bounds
- Phenomenological classes
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RG Effects and Leading Directions

RG Effects: improved analysis of the EFT bounds

comparable/stronger bound compared to the tree-level constraints

Main idea: identify the set of leading directions for which the RG-induced effects offer

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RG Effects: improved analysis of the EFT bounds

- Main idea: identify the set of leading directions for which the RG-induced effects offer comparable/stronger bound compared to the tree-level constraints
- Starting point: Subset of SMEFT operators from the MFV basis
- RG-induced effects introduce a new set of observables:
 - Flavor observables $(b \rightarrow s\ell\ell, \epsilon'/\epsilon)$
 - Z pole observables
 - W mass
 - β -decay
 - Atomic parity violation (APV)

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Label	Operator
$\mathcal{O}_{qq}^{(1)D}$	$(ar q_i\gamma^\mu q^i)(ar q_j\gamma_\mu q^j)$
${\cal O}_{qq}^{(3)D}$	$(ar{q}_i\gamma^\mu\sigma^a q^i)(ar{q}_j\gamma_\mu\sigma^a q^j)$
${\cal O}_{qq}^{(1)E}$	$(ar q_i\gamma^\mu q^j)(ar q_j\gamma_\mu q^i)$
${\cal O}_{qq}^{(3)E}$	$(ar q_i\gamma^\mu\sigma^a q^j)(ar q_j\gamma_\mu\sigma^a q^i)$
${\cal O}^D_{dd}$	$(ar{d}_i\gamma^\mu d^i)(ar{d}_j\gamma_\mu d^j)$
${\cal O}^E_{dd}$	$(ar{d}_i\gamma^\mu d^j)(ar{d}_j\gamma_\mu d^i)$
${\cal O}^{D}_{uu}$	$(ar{u}_i\gamma^\mu u^i)(ar{u}_j\gamma_\mu u^j)$
${\cal O}^E_{uu}$	$(ar{u}_i\gamma^\mu u^j)(ar{u}_j\gamma_\mu u^i)$
${\cal O}_{ud}^{(1)}$	$(ar{u}_i\gamma^\mu u^i)(ar{d}_j\gamma_\mu d^j)$
${\cal O}^{(8)}_{ud}$	$(ar{u}_i\gamma^\mu T^A u^i)(ar{d}_j\gamma_\mu T^A d^j)$
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${\cal O}_{qd}^{(1)}$	$(ar q_i\gamma^\mu q^i)(ar d_j\gamma_\mu d^j)$
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• Relevant set of operators:





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- Relevant set of operators:
 - Four-quark operators







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- Relevant set of operators:
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 - Two-quark operators





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- Relevant set of operators:
 - Four-quark operators
 - Two-quark operators
 - **Remaining operators** •





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- Relevant set of operators:
 - Four-quark operators
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 - **Remaining operators** \bullet
- RG mixing diagrams:
 - Four-quark operators mixing into EW boson vertex
 - Four-quark operators mixing with 2 insertions of Yukawa
 - Four-quark operators mixing into semileptonic operators





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- RG mixing diagrams: •
 - Four-quark operators mixing into EW boson vertex
 - Four-quark operators mixing with 2 insertions of Yukawa
 - Four-quark operators mixing into semileptonic operators
- Application to low-energy observables







- Four-quark operators mixing into EW boson vertex •
- Representative diagram









- Four-quark operators mixing into EW boson vertex •
- Representative diagram and RG equations



$$\begin{split} \dot{C}_{\phi q}^{(1)} &= C_{\phi q,FV}^{(1)} [Y_u Y_u^{\dagger}]_{pr} + C_{\phi q,FD}^{(1)} \delta_{pr} \\ \dot{C}_{\phi q}^{(3)} &= C_{\phi q,FV}^{(3)} [Y_u Y_u^{\dagger}]_{pr} + C_{\phi q,FD}^{(3)} \delta_{pr} \\ \dot{C}_{\phi u}_{pr} &= C_{\phi u,FD}^1 [Y_u^{\dagger} Y_u]_{pr} + C_{\phi u,FD}^2 \delta_{pr} \\ \dot{C}_{\phi d}_{pr} &= C_{\phi d,FD} \delta_{pr} \end{split}$$







- Four-quark operators mixing into EW boson vertex •
- Representative diagram and RG equations



$$\begin{split} \dot{C}_{\phi q,FV}^{(1)} &\equiv 2C_{qq}^{(1)D} + 6C_{qq}^{(3)D} + 12C_{qq}^{(1)E} - C_{\phi u} + 4C_{\phi q}^{(1)} - 9C_{\phi q}^{(3)} \\ \dot{C}_{\phi q}^{(1)} &= C_{\phi q,FV}^{(1)} [Y_{u}Y_{u}^{\dagger}]_{pr} + C_{\phi q,FD}^{(1)} \delta_{pr} \\ \dot{C}_{\phi q}^{(3)} &= C_{\phi q,FV}^{(3)} [Y_{u}Y_{u}^{\dagger}]_{pr} + C_{\phi q,FD}^{(3)} \delta_{pr} \\ \dot{C}_{\phi u}^{(1)} &= C_{\phi u,FD}^{(1)} [Y_{u}^{\dagger}Y_{u}]_{pr} + C_{\phi u,FD}^{2} \delta_{pr} \\ \dot{C}_{\phi d}^{(1)} &= C_{\phi d,FD}^{(1)} \delta_{pr} \\ \dot{C}_{\phi d,FD}^{(1)} &= 6(C_{qd}^{(1)} - C_{ud}^{(1)} + C_{\phi d})y_{t}^{2} \end{split}$$







- Four-quark operators mixing with 2 insertions of Yukawa •
- Representative diagram









- Four-quark operators mixing with 2 insertions of Yukawa •
- Representative diagram and RG equations



$$\dot{C}_{qu}^{(1)} = C_{qu,FV}^{(1)} [Y_u Y_u^{\dagger}]_{pr} \delta_{st} \qquad \dot{C}_{qd}^{(1)} = C_{qd,FV}^{(1)} [Y_u Y_u^{\dagger}]_{pr} \delta_{st}$$
$$\dot{C}_{qu}^{(8)} = C_{qu,FV}^{(8)} [Y_u Y_u^{\dagger}]_{pr} \delta_{st} \qquad \dot{C}_{qd}^{(8)} = C_{qd,FV}^{(8)} [Y_u Y_u^{\dagger}]_{pr} \delta_{st}$$







- Four-quark operators mixing with 2 insertions of Yukawa •
- Representative diagram and RG equations •



$$\dot{C}_{qu,FV}^{(1)} \equiv C_{qu}^{(1)} - \frac{2}{3}C_{uu}^{E} - 2C_{uu}^{D}$$

$$\dot{C}_{qu}^{(1)} = C_{qu,FV}^{(1)}[Y_{u}Y_{u}^{\dagger}]_{pr}\delta_{st} \qquad \dot{C}_{qd}^{(1)} = C_{qd,FV}^{(1)}[Y_{u}Y_{u}^{\dagger}]_{pr}\delta_{st}$$

$$\dot{C}_{qu}^{(8)} = C_{qu,FV}^{(8)}[Y_{u}Y_{u}^{\dagger}]_{pr}\delta_{st} \qquad \dot{C}_{qd}^{(8)} = C_{qd,FV}^{(8)}[Y_{u}Y_{u}^{\dagger}]_{pr}\delta_{st}$$

$$\dot{C}_{qu,FV}^{(8)} \equiv C_{qu,FV}^{(8)} = C_{qu,FV}^{(8)} - 4C_{uu}^{E}$$







- Four-quark operators mixing into semileptonic operators •
- Representative diagram









- Four-quark operators mixing into semileptonic operators •
- Representative diagram and RG equation



 $\dot{C}_{\ell q}^{(3)} = g_2^2 C_{\ell q, FD}^{(3)} \delta_{pr} \delta_{st}$







- Four-quark operators mixing into semileptonic operators •
- Representative diagram and RG equation



$$\dot{C}_{\ell q}^{(3)} = g_2^2 C_{\ell q, FD}^{(3)} \delta_{pr} \delta_{st}$$

$$C_{\ell q, FD}^{(3)} \equiv \frac{2}{3} \left(C_{qq}^{(1)D} + 3C_{qq}^{(1)E} + 17C_{qq}^{(3)D} + 3C_{qq}^{(3)E} \right)$$







- RG equations are solved in the leading log (LL) approximation
- Low-energy observables expressed in terms of the linear combinations of the Wilson coefficients from the MFV basis

Greljo, AP, Smolkovič [2312.09179]



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- RG equations are solved in the leading log (LL) approximation
- Low-energy observables expressed in terms of the linear combinations of the Wilson coefficients from the MFV basis
- $b \rightarrow s\ell\ell$

 $\mathcal{H}_{eff.} \supset -\frac{4G_F}{\sqrt{2}} \frac{\alpha}{4\pi} V_{ts}^* V_{tb} (C_9 \mathcal{O}_9 + C_{10} \mathcal{O}_{10}) + \text{h.c.}$









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$$\mathcal{O}_9 = (\bar{\ell}\gamma_\mu\ell)(\bar{s}_L\gamma^\mu b_L), \quad \mathcal{O}_{10} = (\bar{\ell}\gamma_\mu\gamma_5\ell)(\bar{s}_L\gamma^\mu b_L)$$









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$$C_{10}^{NP} = -\frac{v^2}{4e^2} y_t^2 \Big(C_{\phi q, FV}^{(1)} + C_{\phi q, FV}^{(3)} \Big) \ln\left(\frac{\mu_i}{\mu_f}\right)$$









- RG equations are solved in the leading log (LL) approximation
- Low-energy observables expressed in terms of the linear combinations of the Wilson coefficients from the MFV basis

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$$b \rightarrow s\ell\ell$$

$$\mathcal{H}_{eff.} \supset -\frac{4G_F}{\sqrt{2}} \frac{\alpha}{4\pi} V_{ts}^* V_{tb} (C_9 \mathcal{O}_9 + C_{10} \mathcal{O}_{10}) + \text{h.c.}$$

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• $\mu_i \sim \mathcal{O}(\text{TeV}), \, \mu_f \sim m_Z$

- C_{10} used as a pseudo-observable
- $C_{10}^{NP} = 0.23 \pm 0.15$

Greljo, Salko, Smolkovič, Stangl [2212.10497]







- RG equations are solved in the leading log (LL) approximation
- Low-energy observables expressed in terms of the linear combinations of the Wilson coefficients from the MFV basis
- β -decay

 $\mathcal{H}_{eff} \supset \frac{4G_F}{\sqrt{2}} \sum_{v=d,s,h} \tilde{V}_{ux}(\bar{u}_L \gamma_\mu x_L)(\bar{e}_L \gamma_\mu \nu_{eL}) + \text{h.c.}$






RG Effects: examples of low-energy observables

- RG equations are solved in the leading log (LL) approximation •
- Low-energy observables expressed in terms of the linear combinations of the Wilson coefficients from the MFV basis
- β -decay

$$\mathcal{H}_{eff} \supset \frac{4G_F}{\sqrt{2}} \sum_{x=d,s,b} \tilde{V}_{ux}(\bar{u}_L \gamma_\mu x_L)(\bar{e}_L \gamma_\mu \nu_{eL}) + \text{h.c.}$$

$$\tilde{V}_{ux} = V_{ux}(1 + \epsilon_L^x)$$







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$$\tilde{V}_{ux} = V_{ux}(1 + \frac{\epsilon_L^x}{\epsilon_L})$$

$$\epsilon_L^x = \frac{v^2}{16\pi^2} \left(g_2^2 C_{\ell q, FD}^{(3)} - C_{\phi q, FD}^{(3)} \right) \ln\left(\frac{\mu_i}{\mu_f}\right)$$







RG Effects: examples of low-energy observables

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$$\tilde{V}_{ux} = V_{ux}(1 + \frac{\epsilon_L^x}{\epsilon_L})$$

$$\epsilon_L^x = \frac{v^2}{16\pi^2} \left(g_2^2 C_{\ell q, FD}^{(3)} - C_{\phi q, FD}^{(3)} \right) \ln\left(\frac{\mu_i}{\mu_f}\right)$$

•
$$\mu_i \sim \mathcal{O}(\text{TeV}), \, \mu_f \sim m_Z$$

Violation of CKM unitarity \bullet

$$\Delta_{CKM} \equiv |\tilde{V}_{ud}|^2 + |\tilde{V}_{us}|^2 + |\tilde{V}_{ub}|^2 - 1$$

•
$$\Delta_{CKM} = (-1.52 \pm 0.70) \times 10^{-3}$$

Cirigliano, Dekens, de Vries, Mereghetti, Tong [2311.00021]







Numerical analysis performed using wilson •

			Scalars								
Field	Irrep	Normalization	Direction	Тор	$b ightarrow s\ell\ell$	arepsilon'/arepsilon	δg_Z	$oldsymbol{eta}$	$oldsymbol{Q}_{\mathrm{W}}^{\mathrm{Cs}}$	m_W	Combined
(1, 2)	$(ar{3}_d, 3_q)$	$- y^d_arphi ^2/(6M^2_arphi)$	${\cal O}_{qd}^{(1)}+6{\cal O}_{qd}^{(8)}$	1.0	-	0.8	0.8	-	0.7	0.3	1.2
$arphi \sim (1, 2)_{rac{1}{2}}$	$(ar{3}_q, 3_u)$	$- y^u_arphi ^2/(6M^2_arphi)$	${\cal O}_{qu}^{(1)}+6{\cal O}_{qu}^{(8)}$	1.7	0.4	1.0	0.8	-	0.5	0.9	1.8
(1 (9 1)	$ar{6}_q$	$ y^{qq}_{\omega_1} ^2/(4M^2_{\omega_1})$	${\cal O}_{qq}^{(1)D} - {\cal O}_{qq}^{(3)D} + {\cal O}_{qq}^{(1)E} - {\cal O}_{qq}^{(3)E}$	1.8	3.6	0.7	2.9	[1.3, 6.4]	0.8	1.6	4.0
$\omega_1 \sim (3, 1)_{-\frac{1}{3}}$	$(ar{3}_d,ar{3}_u)$	$ y^{du}_{\omega_1} ^2/(3M^2_{\omega_1})$	${\cal O}^{(1)}_{ud} - 3 {\cal O}^{(8)}_{ud}$	1.1	-	0.8	0.9	-	0.9	0.4	1.5
$\omega_2 \sim ({f 3},{f 1})_{2\over 3}$	3_d	$ y_{\omega_2} ^2/M_{\omega_2}^2$	$\mathcal{O}^{D}_{dd} - \mathcal{O}^{E}_{dd}$	0.4	-	-	0.4	-	-	-	0.5
$\omega_4 \sim ({f 3},{f 1})_{-rac{4}{3}}$	3_{u}	$ y^{uu}_{\omega_4} ^2/M^2_{\omega_4}$	${\cal O}^D_{uu}-{\cal O}^E_{uu}$	1.8	-	1.3	1.1	-	1.7	0.3	1.9
$\zeta \sim (3,3)_{-rac{1}{3}}$	3_q	$ y_\zeta^{qq} ^2/(2M_\zeta^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$	3.1	2.5	0.8	1.2	4.1	2.0	0.5	3.7
$\Omega_1 \sim (6, 1)_1$	$({f 3}_u,{f 3}_d)$	$ y^{ud}_{\Omega_1} ^2/(6M^2_{\Omega_1})$	$2 {\cal O}_{ud}^{(1)} + 3 {\cal O}_{ud}^{(8)}$	1.0	-	0.5	0.8	-	0.9	0.3	1.4
$321 \times (0, 1)_{\frac{1}{3}}$	$ar{3}_q$	$ y^{qq}_{\Omega_1} ^2/(4M^2_{\Omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} - \mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$	2.1	2.5	0.9	2.4	[1.7, 8.3]	1.1	0.6	2.6
$\Omega_2 \sim ({f 6},{f 1})_{-rac{2}{3}}$	6_{d}	$ y_{\Omega_2} ^2/(4M_{\Omega_2}^2)$	$\mathcal{O}^{D}_{dd} + \mathcal{O}^{E}_{dd}$	0.2	-	-	0.3	-	-	-	0.3
$\Omega_4 \sim ({f 6},{f 1})_{4\over 3}$	6_{u}	$ y_{\Omega_4} ^2/(4M_{\Omega_4}^2)$	${\cal O}^D_{uu} + {\cal O}^E_{uu}$	1.3	0.3	1.0	0.8	-	1.1	1.7	2.1
$\Upsilon \sim ({f 6},{f 3})_{1\over 3}$	6_q	$ y_{\Upsilon} ^2/(8M_{\Upsilon}^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} + 3\mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$	1.7	3.0	0.7	2.8	2.7	1.3	2.2	4.8
መ ል (ዩ ን) -	$(ar{3}_q, 3_u)$	$- y^{qu}_{\Phi} ^2/(18M_{\Phi}^2)$	$4 {\cal O}_{qu}^{(1)} - 3 {\cal O}_{qu}^{(8)}$	1.2	0.2	0.1	0.9	-	0.5	1.0	1.5
$\Psi \sim (0, 2)_{\frac{1}{2}}$	$(ar{3}_d, 3_q)$	$- y_{\Phi}^{dq} ^2/(18M_{\Phi}^2)$	$4 {\cal O}_{qd}^{(1)} - 3 {\cal O}_{qd}^{(8)}$	0.8	-	0.1	0.8	-	0.7	0.3	1.2



Aebischer, Kumar, Straub [1804.05033]







Numerical analysis performed using wilson •

			Scalars								
Field	Irrep	Normalization	Direction	Тор	$b ightarrow s\ell\ell$	arepsilon'/arepsilon	δg_Z	$oldsymbol{eta}$	$oldsymbol{Q}_{\mathrm{W}}^{\mathrm{Cs}}$	m_W	Combined
(1.2)	$(ar{3}_d, 3_q)$	$- y^d_arphi ^2/(6M^2_arphi)$	${\cal O}_{qd}^{(1)}+6{\cal O}_{qd}^{(8)}$	1.0	-	0.8	0.8	-	0.7	0.3	1.2
$arphi \sim (1, 2)_{rac{1}{2}}$	$(ar{3}_q, 3_u)$	$- y^u_arphi ^2/(6M^2_arphi)$	${\cal O}_{qu}^{(1)}+6{\cal O}_{qu}^{(8)}$	1.7	0.4	1.0	0.8	-	0.5	0.9	1.8
(1 (9 1)	$ar{6}_q$	$ y^{qq}_{\omega_1} ^2/(4M^2_{\omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} + \mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$	1.8	3.6	0.7	2.9	[1.3, 6.4]	0.8	1.6	4.0
$\omega_1 \sim (3, 1)_{-rac{1}{3}}$	$(ar{3}_d,ar{3}_u)$	$ y^{du}_{\omega_1} ^2/(3M^2_{\omega_1})$	${\cal O}_{ud}^{(1)} - 3 {\cal O}_{ud}^{(8)}$	1.1	-	0.8	0.9	-	0.9	0.4	1.5
$\omega_2 \sim ({f 3},{f 1})_{2\over 3}$	3_d	$ y_{\omega_2} ^2/M_{\omega_2}^2$	$\mathcal{O}^{D}_{dd} - \mathcal{O}^{E}_{dd}$	0.4	-	-	0.4	-	-	-	0.5
$\omega_4 \sim \left({f 3}, {f 1} ight)_{-rac{4}{3}}$	3_{u}	$ y^{uu}_{\omega_4} ^2/M^2_{\omega_4}$	${\cal O}^D_{uu}-{\cal O}^E_{uu}$	1.8	-	1.3	1.1	-	1.7	0.3	1.9
$\zeta \sim ({f 3},{f 3})_{-rac{1}{3}}$	3_q	$ y_\zeta^{qq} ^2/(2M_\zeta^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$	3.1	2.5	0.8	1.2	4.1	2.0	0.5	3.7
$Q_1 \sim (6, 1)_1$	$(3_u,3_d)$	$ y^{ud}_{\Omega_1} ^2/(6M^2_{\Omega_1})$	$2\mathcal{O}_{ud}^{(1)} + 3\mathcal{O}_{ud}^{(8)}$	1.0	-	0.5	0.8	-	0.9	0.3	1.4
$\frac{321}{3}$	$ar{3}_q$	$ y^{qq}_{\Omega_1} ^2/(4M^2_{\Omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} - \mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$	2.1	2.5	0.9	2.4	[1.7, 8.3]	1.1	0.6	2.6
$\Omega_2 \sim (6, 1)_{-rac{2}{3}}$	6_d	$ y_{\Omega_2} ^2/(4M_{\Omega_2}^2)$	$\mathcal{O}^{D}_{dd} + \mathcal{O}^{E}_{dd}$	0.2	-	-	0.3	-	-	-	0.3
$\Omega_4 \sim ({f 6},{f 1})_{4\over 3}$	6_{u}	$ y_{\Omega_4} ^2/(4M_{\Omega_4}^2)$	${\cal O}^D_{uu}+{\cal O}^E_{uu}$	1.3	0.3	1.0	0.8	-	1.1	1.7	2.1
$\Upsilon \sim ({f 6},{f 3})_{1\over 3}$	6_q	$ y_{\Upsilon} ^2/(8M_{\Upsilon}^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} + 3\mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$	1.7	3.0	0.7	2.8	2.7	1.3	2.2	4.8
	$(ar{3}_q, 3_u)$	$- y^{qu}_{\Phi} ^2/(18 M_{\Phi}^2)$	$4 {\cal O}_{qu}^{(1)} - 3 {\cal O}_{qu}^{(8)}$	1.2	0.2	0.1	0.9	-	0.5	1.0	1.5
$\Psi \sim (0, \mathbf{Z})_{\frac{1}{2}}$	$(ar{3}_d, 3_q)$	$- y_{\Phi}^{dq} ^2/(18M_{\Phi}^2)$	$4\mathcal{O}_{qd}^{(1)} - 3\mathcal{O}_{qd}^{(8)}$	0.8	-	0.1	0.8	-	0.7	0.3	1.2



Aebischer, Kumar, Straub [1804.05033]







Numerical analysis performed using wilson •

			Scalars								
Field	Irrep	Normalization	Direction	Тор	$b ightarrow s\ell\ell$	arepsilon'/arepsilon	δg_Z	$oldsymbol{eta}$	$oldsymbol{Q}_{\mathrm{W}}^{\mathrm{Cs}}$	m_W	Combined
(1 , 2)	$(ar{3}_d, 3_q)$	$- y^d_arphi ^2/(6M^2_arphi)$	${\cal O}_{qd}^{(1)}+6{\cal O}_{qd}^{(8)}$	1.0	-	0.8	0.8	-	0.7	0.3	1.2
$arphi \sim (1, 2)_{rac{1}{2}}$	$(ar{3}_q, 3_u)$	$- y^u_arphi ^2/(6M^2_arphi)$	${\cal O}_{qu}^{(1)}+6{\cal O}_{qu}^{(8)}$	1.7	0.4	1.0	0.8	-	0.5	0.9	1.8
(1, 2, (2, 1))	$ar{6}_q$	$ y^{qq}_{\omega_1} ^2/(4M^2_{\omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} + \mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$	1.8	3.6	0.7	2.9	[1.3,6.4]	0.8	1.6	4.0
$\omega_1 \sim (3, 1)_{-\frac{1}{3}}$	$(ar{3}_d, ar{3}_u)$	$ y^{du}_{\omega_1} ^2/(3M^2_{\omega_1})$	${\cal O}_{ud}^{(1)} - 3 {\cal O}_{ud}^{(8)}$	1.1	-	0.8	0.9	-	0.9	0.4	1.5
$\omega_2 \sim ({f 3},{f 1})_{2\over 3}$	3_d	$ y_{\omega_2} ^2/M_{\omega_2}^2$	$\mathcal{O}^{D}_{dd} - \mathcal{O}^{E}_{dd}$	0.4	-	-	0.4	-	-	-	0.5
$\omega_4 \sim \left(3, 1 ight)_{-rac{4}{3}}$	3_{u}	$ y^{uu}_{\omega_4} ^2/M^2_{\omega_4}$	${\cal O}^D_{uu}-{\cal O}^E_{uu}$	1.8	-	1.3	1.1	-	1.7	0.3	1.9
$\zeta \sim (3,3)_{-rac{1}{3}}$	3_q	$ y_\zeta^{qq} ^2/(2M_\zeta^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$	3.1	2.5	0.8	1.2	4.1	2.0	0.5	3.7
$\Omega_1 \sim (6, 1)_1$	$(3_u,3_d)$	$ y^{ud}_{\Omega_1} ^2/(6M^2_{\Omega_1})$	$2\mathcal{O}_{ud}^{(1)} + 3\mathcal{O}_{ud}^{(8)}$	1.0	-	0.5	0.8	-	0.9	0.3	1.4
$(0, 1)_{\frac{1}{3}}$	$ar{3}_q$	$ y^{qq}_{\Omega_1} ^2/(4M^2_{\Omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} - \mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$	2.1	2.5	0.9	2.4	[1.7, 8.3]	1.1	0.6	2.6
$\Omega_2 \sim ({f 6},{f 1})_{-rac{2}{3}}$	6_d	$ y_{\Omega_2} ^2/(4M_{\Omega_2}^2)$	$\mathcal{O}^{D}_{dd} + \mathcal{O}^{E}_{dd}$	0.2	-	-	0.3	-	-	-	0.3
$\Omega_4 \sim ({f 6},{f 1})_{4\over 3}$	6_{u}	$ y_{\Omega_4} ^2/(4M_{\Omega_4}^2)$	${\cal O}^D_{uu}+{\cal O}^E_{uu}$	1.3	0.3	1.0	0.8	-	1.1	1.7	2.1
$\Upsilon \sim ({f 6},{f 3})_{1\over 3}$	6_q	$ y_{\Upsilon} ^2/(8M_{\Upsilon}^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} + 3\mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$	1.7	3.0	0.7	2.8	2.7	1.3	2.2	4.8
መ (ዓ ዓ)	$(ar{3}_q, 3_u)$	$- y^{qu}_{\Phi} ^2/(18M_{\Phi}^2)$	$4 {\cal O}_{qu}^{(1)} - 3 {\cal O}_{qu}^{(8)}$	1.2	0.2	0.1	0.9	-	0.5	1.0	1.5
$\Psi \sim (0, 2)_{\frac{1}{2}}$	$(ar{3}_d, 3_q)$	$- y_{\Phi}^{dq} ^2/(18M_{\Phi}^2)$	$4 {\cal O}_{qd}^{(1)} - 3 {\cal O}_{qd}^{(8)}$	0.8	-	0.1	0.8	-	0.7	0.3	1.2



Aebischer, Kumar, Straub [1804.05033]







Numerical analysis performed using wilson •

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(1.0)	$(ar{3}_d, 3_q)$	$- y^d_arphi ^2/(6M^2_arphi)$	${\cal O}_{qd}^{(1)}+6{\cal O}_{qd}^{(8)}$	1.0	-	0.8	0.8	-	0.7	0.3	1.2
$arphi \sim (1, 2)_{rac{1}{2}}$	$(ar{3}_q, 3_u)$	$- y^u_arphi ^2/(6M^2_arphi)$	${\cal O}_{qu}^{(1)}+6{\cal O}_{qu}^{(8)}$	1.7	0.4	1.0	0.8	-	0.5	0.9	1.8
(9.1)	$ar{6}_q$	$ y^{qq}_{\omega_1} ^2/(4M^2_{\omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} + \mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$	1.8	3.6	0.7	2.9	[1.3, 6.4]	0.8	1.6	4.0
$\omega_1 \sim (3, 1)_{-\frac{1}{3}}$	$(ar{3}_d,ar{3}_u)$	$ y^{du}_{\omega_1} ^2/(3M^2_{\omega_1})$	${\cal O}_{ud}^{(1)} - 3 {\cal O}_{ud}^{(8)}$	1.1	-	0.8	0.9	-	0.9	0.4	1.5
$\omega_2 \sim ({f 3},{f 1})_{2\over 3}$	3_d	$ y_{\omega_2} ^2/M_{\omega_2}^2$	$\mathcal{O}^{D}_{dd} - \mathcal{O}^{E}_{dd}$	0.4	-	-	0.4	-	-	-	0.5
$\omega_4 \sim \left({f 3}, {f 1} ight)_{-rac{4}{3}}$	3_{u}	$ y^{uu}_{\omega_4} ^2/M^2_{\omega_4}$	${\cal O}^D_{uu}-{\cal O}^E_{uu}$	1.8	-	1.3	1.1	-	1.7	0.3	1.9
$\zeta \sim (3,3)_{-rac{1}{3}}$	3_q	$ y_\zeta^{qq} ^2/(2M_\zeta^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$	3.1	2.5	0.8	1.2	4.1	2.0	0.5	3.7
$\Omega_1 \sim (6, 1)_1$	$(3_u,3_d)$	$ y^{ud}_{\Omega_1} ^2/(6M^2_{\Omega_1})$	$2 {\cal O}_{ud}^{(1)} + 3 {\cal O}_{ud}^{(8)}$	1.0	-	0.5	0.8	-	0.9	0.3	1.4
$(0, 1)_{\frac{1}{3}}$	$ar{3}_q$	$ y^{qq}_{\Omega_1} ^2/(4M^2_{\Omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} - \mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$	2.1	2.5	0.9	2.4	[1.7, 8.3]	1.1	0.6	2.6
$\Omega_2 \sim ({f 6},{f 1})_{-rac{2}{3}}$	6_d	$ y_{\Omega_2} ^2/(4M_{\Omega_2}^2)$	${\cal O}^{D}_{dd}+{\cal O}^{E}_{dd}$	0.2	-	-	0.3	-	-	-	0.3
$\Omega_4 \sim ({f 6},{f 1})_{4\over 3}$	6_{u}	$ y_{\Omega_4} ^2/(4M_{\Omega_4}^2)$	${\cal O}^D_{uu}+{\cal O}^E_{uu}$	1.3	0.3	1.0	0.8	-	1.1	1.7	2.1
$\Upsilon \sim ({f 6},{f 3})_{1\over 3}$	6_q	$ y_{\Upsilon} ^2/(8M_{\Upsilon}^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} + 3\mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$	1.7	3.0	0.7	2.8	2.7	1.3	2.2	4.8
<u>አ</u> (የ ባ)	$(ar{3}_q, 3_u)$	$- y^{qu}_{\Phi} ^2/(18M^2_{\Phi})$	$4 {\cal O}_{qu}^{(1)} - 3 {\cal O}_{qu}^{(8)}$	1.2	0.2	0.1	0.9	-	0.5	1.0	1.5
$\Psi \sim (8, 2)_{rac{1}{2}}$	$(ar{3}_d, 3_q)$	$- y_{\Phi}^{dq} ^2/(18M_{\Phi}^2)$	$4 \mathcal{O}_{qd}^{(1)} - 3 \mathcal{O}_{qd}^{(8)}$	0.8	-	0.1	0.8	-	0.7	0.3	1.2



Aebischer, Kumar, Straub [1804.05033]







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SMEFT $\mathcal{O}(1)$ terms			Lepton sector														
$(ext{dim-6}, \Delta B = 0)$		MF	V_L	$U(3)_V$ $U(2)^2 \times U(2)^2$		$\times U(1)^2$	$U(2)^{2}$		$\mathrm{U}(2)_V$		$U(1)^{6}$		$U(1)^{3}$		No symm.		
	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
Oranla	$\mathrm{U}(2)^2 imes \mathrm{U}(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
Quark	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
sector	$U(2)^{3}$	93	17	100	23	118	17	124	23	132	30	147	17	168	38	321	191
	No symmetry	703	570	734	600	756	591	786	621	818	652	813	612	906	705	1350	1149

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$egin{aligned} &\omega_2\sim ({f 3},{f 1})_{rac{2}{3}} \ &\omega_4\sim ({f 3},{f 1})_{-rac{4}{3}} \end{aligned}$	${f 3}_d \ {f 3}_u$	$ y_{\omega_2} ^2/M_{\omega_2}^2 \ y_{\omega_4}^{uu} ^2/M_{\omega_4}^2$	$egin{aligned} \mathcal{O}^{D}_{dd} &- \mathcal{O}^{E}_{dd} \ \mathcal{O}^{D}_{uu} &- \mathcal{O}^{E}_{uu} \end{aligned}$	0.4 1.8	-	- 1.3	0.4 1.1	-	- 1.7	- 0.3	0.5 1.9
$\zeta \sim (3,3)_{-rac{1}{3}}$	3_q	$ y_\zeta^{qq} ^2/(2M_\zeta^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} - 3\mathcal{O}_{qq}^{(1)E} - \mathcal{O}_{qq}^{(3)E}$	3.1	2.5	0.8	1.2	4.1	2.0	0.5	3.7
$\Omega_1 \sim (6, 1)_1$	$(3_u,3_d)$	$ y^{ud}_{\Omega_1} ^2/(6M^2_{\Omega_1})$	$2{\cal O}^{(1)}_{ud}+3{\cal O}^{(8)}_{ud}$	1.0	-	0.5	0.8	-	0.9	0.3	1.4
$\frac{321}{3}$	$ar{3}_q$	$ y^{qq}_{\Omega_1} ^2/(4M^2_{\Omega_1})$	$\mathcal{O}_{qq}^{(1)D} - \mathcal{O}_{qq}^{(3)D} - \mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$	2.1	2.5	0.9	2.4	[1.7, 8.3]	1.1	0.6	2.6
$\Omega_2 \sim \left({f 6}, {f 1} ight)_{-rac{2}{3}}$	6_{d}	$ y_{\Omega_2} ^2/(4M_{\Omega_2}^2)$	$\mathcal{O}_{dd}^{D}+\mathcal{O}_{dd}^{E}$	0.2	-	-	0.3	-	-	-	0.3
$\Omega_4 \sim ({f 6},{f 1})_{4\over 3}$	6_{u}	$ y_{\Omega_4} ^2/(4M_{\Omega_4}^2)$	${\cal O}^D_{uu}+{\cal O}^E_{uu}$	1.3	0.3	1.0	0.8	-	1.1	1.7	2.1
$\Upsilon \sim ({f 6},{f 3})_{1\over 3}$	${f 6}_q$	$ y_{\Upsilon} ^2/(8M_{\Upsilon}^2)$	$3\mathcal{O}_{qq}^{(1)D} + \mathcal{O}_{qq}^{(3)D} + 3\mathcal{O}_{qq}^{(1)E} + \mathcal{O}_{qq}^{(3)E}$	1.7	3.0	0.7	2.8	2.7	1.3	2.2	4.8
$\Phi \sim (old 8, old 2)_{rac{1}{2}}$	$(ar{3}_q, 3_u)$	$- y^{qu}_{\Phi} ^2/(18M_{\Phi}^2)$	$4 {\cal O}_{qu}^{(1)} - 3 {\cal O}_{qu}^{(8)}$	1.2	0.2	0.1	0.9	-	0.5	1.0	1.5
	$(ar{3}_d, 3_q)$	$- y_{\Phi}^{dq} ^2/(18M_{\Phi}^2)$	$4 {\cal O}_{qd}^{(1)} - 3 {\cal O}_{qd}^{(8)}$	0.8	-	0.1	0.8	-	0.7	0.3	1.2