Leading Directions in SMEFT

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In collaboration with: Admir Greljo and Anders Eller Thomsen

Based on arXiv: [2203.09561] and [2305.08898]

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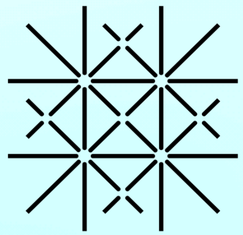
CERN, 17.11.2023.



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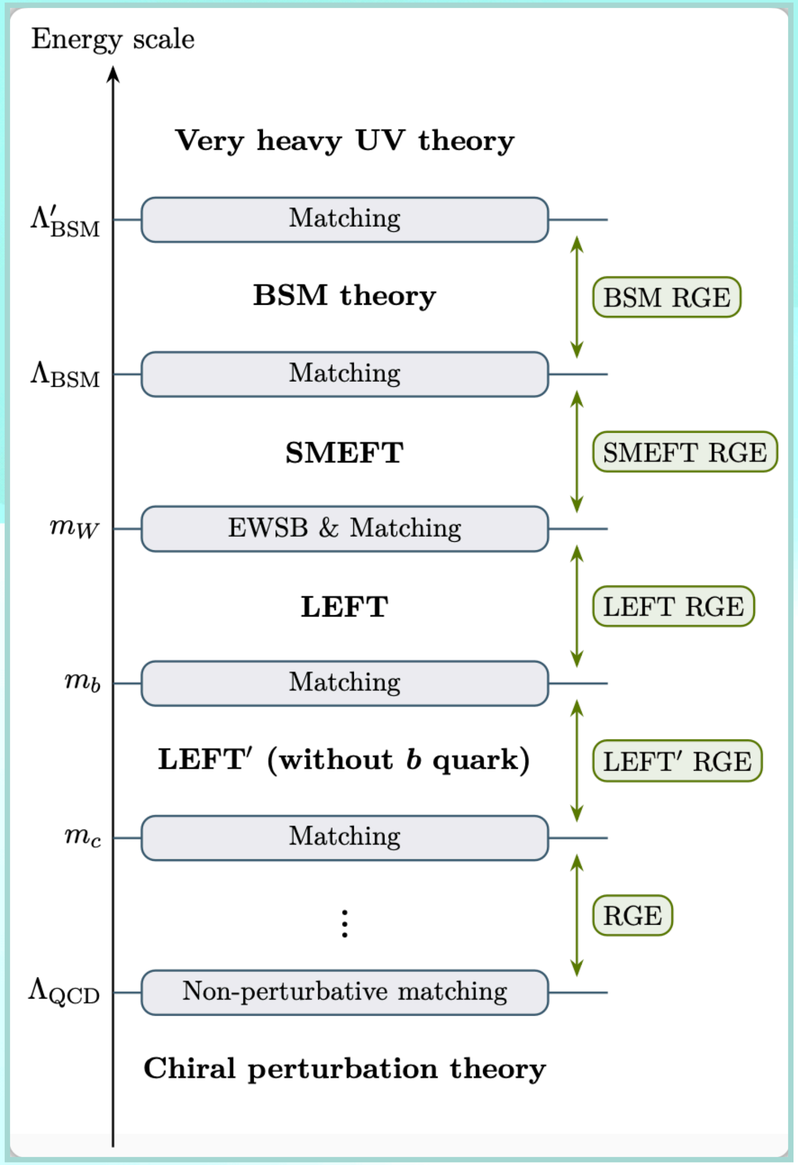
Introduction

Introduction: EFT general perspective



- Inclusion of the effects of the new physics in an EFT description

$$\mathscr{L}_{\rm EFT} = \mathscr{L}^{d=4} + \sum_{d=5}^{\infty} \sum_{k} \frac{C^{(d,k)}}{\Lambda^{d-4}} \mathcal{O}^{(d,k)}$$

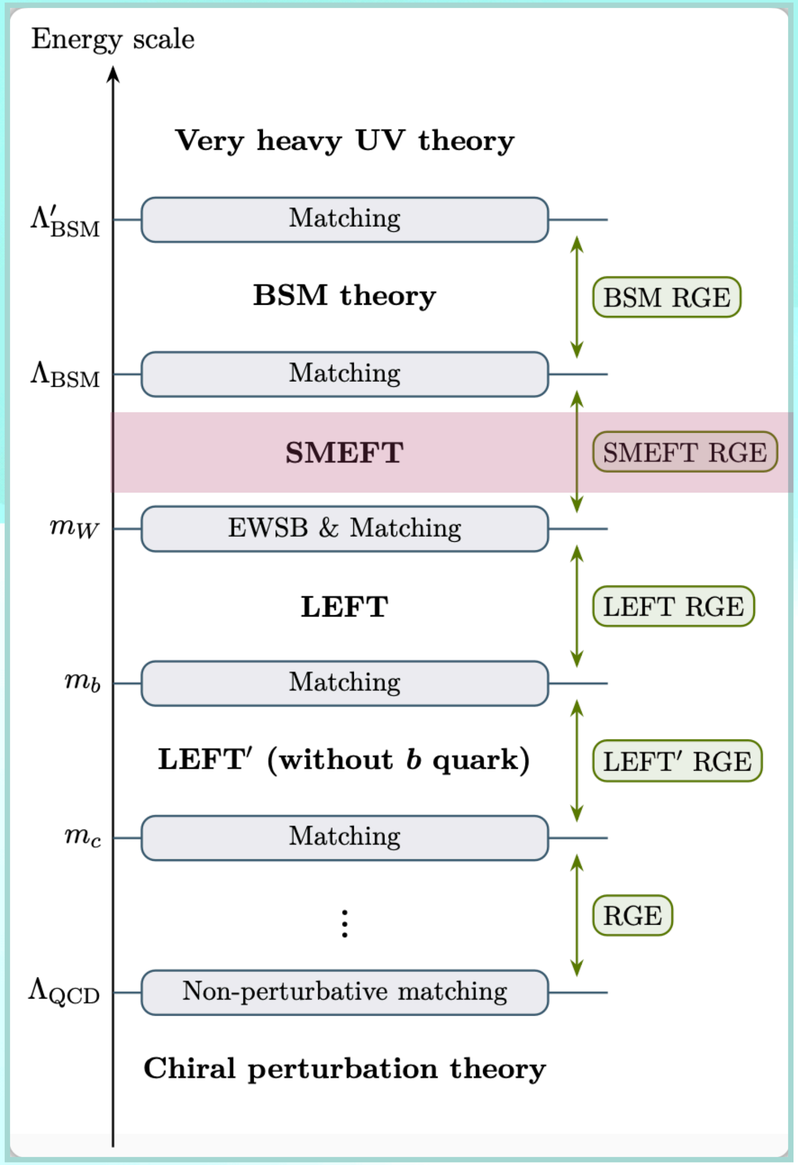
- Wilson coefficients $C^{(d,k)}$ contain the information on the UV physics

- Two distinct approaches in the construction of the EFTs

  - Bottom-up: model-independent analysis with deviations quantified as the E/Λ expansion

  - Top-down: starting from a higher scale, facilitate the precision computations in order to move towards the lower scales

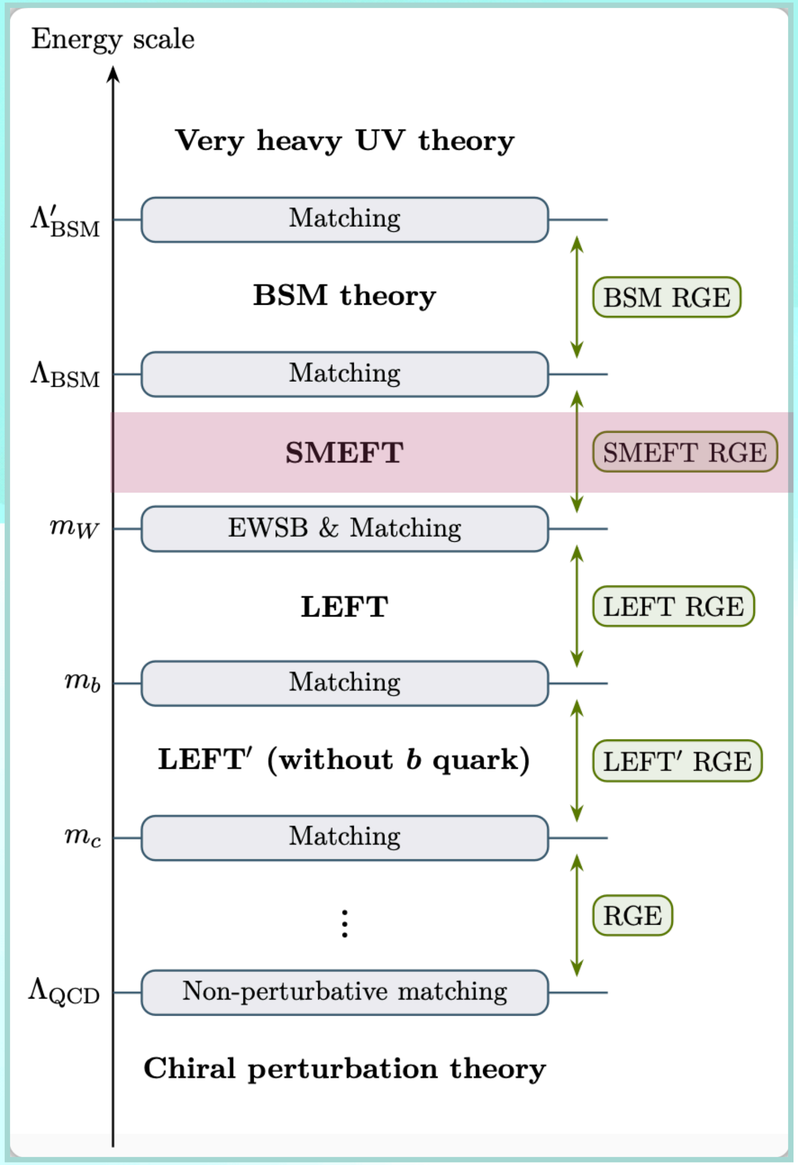
Introduction: SMEFT



- 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

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

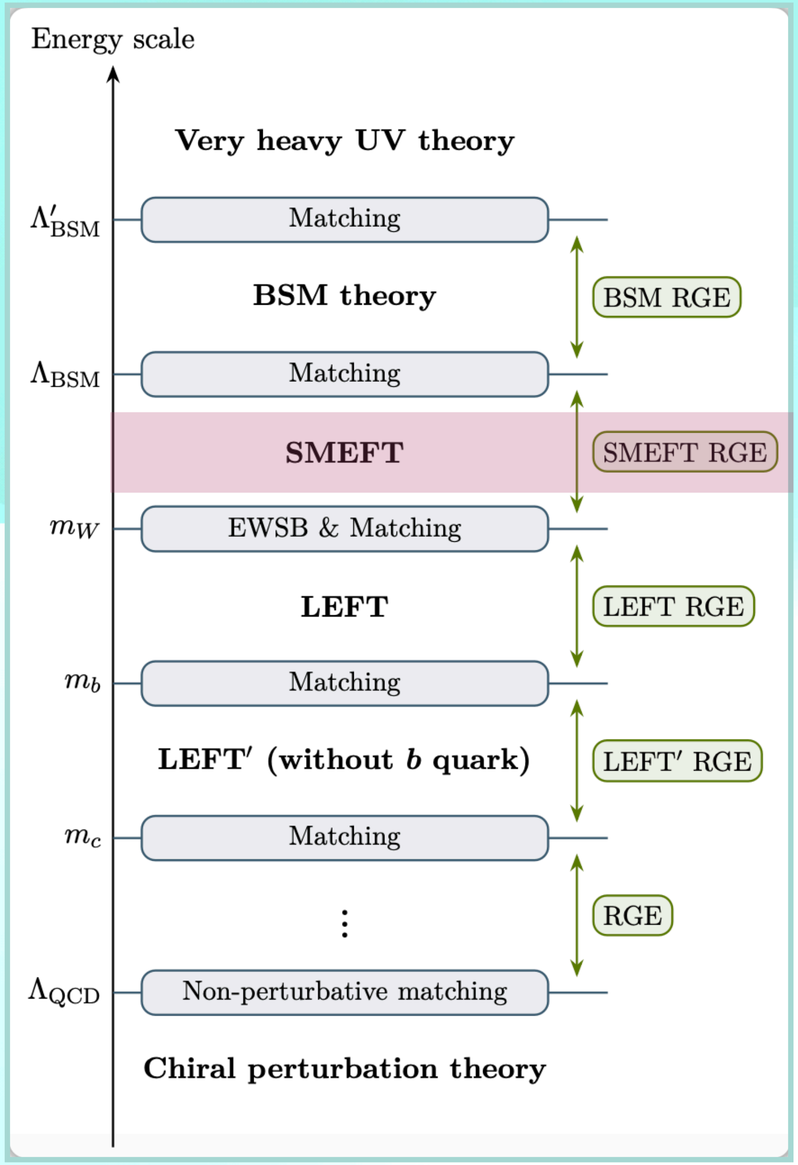
Introduction: SMEFT operators and bases



- Higher-dimensional operators are collected in the non-redundant 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]

SYM2INT

Introduction: SMEFT operators and bases



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SYM2INT

Introduction: dimension-6 operators

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

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star\left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I\varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\, \widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{\varphi}\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{e}_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\, \widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{\varphi}\, W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{q}_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{\varphi}\, B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\, \widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{d}_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}^I_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}_p\gamma^\mu d_r)$

$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q^{(1)}_{qq}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$Q^{(3)}_{qq}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$Q^{(1)}_{lq}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
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		$Q^{(1)}_{ud}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$Q^{(8)}_{qu}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$Q^{(8)}_{ud}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$Q^{(1)}_{qd}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
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$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating			
Q_{ledq}	$(\bar{l}^j_p e_r)(\bar{d}_s q^j_t)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(q^{\gamma j}_s)^T C l^k_t\right]$		
$Q^{(1)}_{quqd}$	$(\bar{q}^j_p u_r)\varepsilon_{jk}(\bar{q}^k_s d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q^{\alpha j}_p)^T C q^{\beta k}_r\right]\left[(u^\gamma_s)^T C e_t\right]$		
$Q^{(8)}_{quqd}$	$(\bar{q}^j_p T^A u_r)\varepsilon_{jk}(\bar{q}^k_s T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q^{\alpha j}_p)^T C q^{\beta k}_r\right]\left[(q^{\gamma m}_s)^T C l^n_t\right]$		
$Q^{(1)}_{lequ}$	$(\bar{l}^j_p e_r)\varepsilon_{jk}(\bar{q}^k_s u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(u^\gamma_s)^T C e_t\right]$		
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- In the Standard Model

$$U(3)^5 = U(3)_q \times U(3)_\ell \times U(3)_u \times U(3)_d \times U(3)_e$$

$$-\mathscr{L}_Y = \bar{q}\, V^\dagger \hat{Y}_u \tilde{\phi} u + \bar{q}\, \hat{Y}_d \phi d + \bar{\ell}\, \hat{Y}_e \phi e$$

$$U(1)_B \times U(1)_e \times U(1)_\mu \times U(1)_\tau$$

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Q_G	$f^{ABC} G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
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Q_W	$\varepsilon^{IJK} W^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu \varphi\right)^\star \left(\varphi^\dagger D_\mu \varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
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$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$
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$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{d}_p \gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$

$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
$Q^{(1)}_{qq}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p \gamma_\mu u_r)(\bar{u}_s \gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
$Q^{(3)}_{qq}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	Q_{dd}	$(\bar{d}_p \gamma_\mu d_r)(\bar{d}_s \gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p \gamma_\mu l_r)(\bar{d}_s \gamma^\mu d_t)$
$Q^{(1)}_{lq}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p \gamma_\mu e_r)(\bar{u}_s \gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p \gamma_\mu q_r)(\bar{e}_s \gamma^\mu e_t)$
$Q^{(3)}_{lq}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	Q_{ed}	$(\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)$	$Q^{(1)}_{qu}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{u}_s \gamma^\mu u_t)$
		$Q^{(1)}_{ud}$	$(\bar{u}_p \gamma_\mu u_r)(\bar{d}_s \gamma^\mu d_t)$	$Q^{(8)}_{qu}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{u}_s \gamma^\mu T^A u_t)$
		$Q^{(8)}_{ud}$	$(\bar{u}_p \gamma_\mu T^A u_r)(\bar{d}_s \gamma^\mu T^A d_t)$	$Q^{(1)}_{qd}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{d}_s \gamma^\mu d_t)$
				$Q^{(8)}_{qd}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{d}_s \gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
Q_{ledq}	$(\bar{l}^j_p e_r)(\bar{d}_s q^j_t)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(q^{\gamma j}_s)^T C l^k_t\right]$
$Q^{(1)}_{quqd}$	$(\bar{q}^j_p u_r)\varepsilon_{jk}(\bar{q}^k_s d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q^{\alpha j}_p)^T C q^{\beta k}_r\right]\left[(u^\gamma_s)^T C e_t\right]$
$Q^{(8)}_{quqd}$	$(\bar{q}^j_p T^A u_r)\varepsilon_{jk}(\bar{q}^k_s T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q^{\alpha j}_p)^T C q^{\beta k}_r\right]\left[(q^{\gamma m}_s)^T C l^n_t\right]$
$Q^{(1)}_{lequ}$	$(\bar{l}^j_p e_r)\varepsilon_{jk}(\bar{q}^k_s u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(u^\gamma_s)^T C e_t\right]$
$Q^{(3)}_{lequ}$	$(\bar{l}^j_p \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar{q}^k_s \sigma^{\mu\nu} u_t)$		

Grzadkowski, Iskrzynski, Misiak, Rosiek [1008.4884]

Introduction: dimension-6 operators

- In the Standard Model

$$U(3)^5 = U(3)_q \times U(3)_\ell \times U(3)_u \times U(3)_d \times U(3)_e$$

$$-\mathscr{L}_Y = \bar{q} V^\dagger \hat{Y}_u \tilde{\phi} u + \bar{q} \hat{Y}_d \phi d + \bar{\ell} \hat{Y}_e \phi e$$

$$U(1)_B \times U(1)_e \times U(1)_\mu \times U(1)_\tau$$

- However, observed mass hierarchy and the CKM alignment point to approximate accidental symmetries

- This is the starting point of our analysis

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK} W^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu \varphi\right)^\star \left(\varphi^\dagger D_\mu \varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK} \widetilde{W}^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$				

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

$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
$Q^{(1)}_{qq}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p \gamma_\mu u_r)(\bar{u}_s \gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
$Q^{(3)}_{qq}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	Q_{dd}	$(\bar{d}_p \gamma_\mu d_r)(\bar{d}_s \gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p \gamma_\mu l_r)(\bar{d}_s \gamma^\mu d_t)$
$Q^{(1)}_{lq}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p \gamma_\mu e_r)(\bar{u}_s \gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p \gamma_\mu q_r)(\bar{e}_s \gamma^\mu e_t)$
$Q^{(3)}_{lq}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	Q_{ed}	$(\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)$	$Q^{(1)}_{qu}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{u}_s \gamma^\mu u_t)$
		$Q^{(1)}_{ud}$	$(\bar{u}_p \gamma_\mu u_r)(\bar{d}_s \gamma^\mu d_t)$	$Q^{(8)}_{qu}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{u}_s \gamma^\mu T^A u_t)$
		$Q^{(8)}_{ud}$	$(\bar{u}_p \gamma_\mu T^A u_r)(\bar{d}_s \gamma^\mu T^A d_t)$	$Q^{(1)}_{qd}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{d}_s \gamma^\mu d_t)$
				$Q^{(8)}_{qd}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{d}_s \gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
Q_{ledq}	$(\bar{l}^j_p e_r)(\bar{d}_s q^j_t)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(q^{\gamma j}_s)^T C l^k_t\right]$
$Q^{(1)}_{quqd}$	$(\bar{q}^j_p u_r)\varepsilon_{jk}(\bar{q}^k_s d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q^{\alpha j}_p)^T C q^{\beta k}_r\right]\left[(u^\gamma_s)^T C e_t\right]$
$Q^{(8)}_{quqd}$	$(\bar{q}^j_p T^A u_r)\varepsilon_{jk}(\bar{q}^k_s T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q^{\alpha j}_p)^T C q^{\beta k}_r\right]\left[(q^{\gamma m}_s)^T C l^n_t\right]$
$Q^{(1)}_{lequ}$	$(\bar{l}^j_p e_r)\varepsilon_{jk}(\bar{q}^k_s u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d^\alpha_p)^T C u^\beta_r\right]\left[(u^\gamma_s)^T C e_t\right]$
$Q^{(3)}_{lequ}$	$(\bar{l}^j_p \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar{q}^k_s \sigma^{\mu\nu} u_t)$		

Grzadkowski, Iskrzynski, Misiak, Rosiek [1008.4884]

Flavor structure of the SMEFT

Viable options

- Subgroups of $U(3)^5$ explored

$$U(3)^5 = U(3)_q \times U(3)_u \times U(3)_d \times U(3)_\ell \times U(3)_e$$

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

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

Viable options: quark and lepton sector

- Subgroups of $U(3)^5$ explored

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Quark sector

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

Lepton sector

- $\mathrm{MFV}_L \equiv U(3)^2$
- $U(3)_V$, $U(2)_V$
- $U(2)^2 \times U(1)^2$, $U(2)^2$
- $U(1)^6$, $U(1)^3$

Greljo, AP, Thomsen [2203.09561]

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

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

28 cases

Lepton sector

- $\text{MFV}_L \equiv U(3)^2$
- $U(3)_V$, $U(2)_V$
- $U(2)^2 \times U(1)^2$, $U(2)^2$
- $U(1)^6$, $U(1)^3$

Greljo, AP, Thomsen [2203.09561]

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 $Y_u \sim (3,\bar{3},1)$ and $Y_d \sim (3,1,\bar{3})$

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X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK} W^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu \varphi\right)^\star \left(\varphi^\dagger D_\mu \varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK} \widetilde{W}^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\, \widetilde{G}^A_{\mu\nu} G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i \overleftrightarrow{D}^I_\mu \varphi)(\bar{l}_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\widetilde{\varphi} G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{e}_p \gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\, \widetilde{W}^I_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \widetilde{\varphi} W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{q}_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{\varphi} B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^\dagger i \overleftrightarrow{D}^I_\mu \varphi)(\bar{q}_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r)\varphi G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{u}_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{d}_p \gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$

Examples of 2ψ flavor invariants

$$(\bar{q}q): \begin{cases} \mathcal{O}(1): & (\bar{q}q) \\ \mathcal{O}(Y_u^2): & (\bar{q}Y_u Y_u^\dagger q) \\ \mathcal{O}(Y_d^2): & (\bar{q}Y_d Y_d^\dagger q) \end{cases}$$

$$(\bar{u}u): \begin{cases} \mathcal{O}(1): & (\bar{u}u) \\ \mathcal{O}(Y_u^2): & (\bar{u}Y_u^\dagger Y_u u) \end{cases}$$

$$(\bar{d}d): \begin{cases} \mathcal{O}(1): & (\bar{d}d) \\ \mathcal{O}(Y_d^2): & (\bar{d}Y_d^\dagger Y_d d) \end{cases}$$

Greljo, AP, Thomsen [2203.09561]

Construction of flavor invariants

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- Fields $q \sim (3,1,1)$, $u \sim (1,3,1)$, $d \sim (1,1,3)$
- Spurions $Y_u \sim (3,\bar{3},1)$ and $Y_d \sim (3,1,\bar{3})$

$(\bar{L}\bar{L})(\bar{L}\bar{L})$		$(\bar{R}\bar{R})(\bar{R}\bar{R})$		$(\bar{L}\bar{L})(\bar{R}\bar{R})$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$(\bar{L}\bar{R})(\bar{R}\bar{L})$ and $(\bar{L}\bar{R})(\bar{L}\bar{R})$		B-violating	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\varepsilon_{jk}(\bar{q}_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\varepsilon_{jk}(\bar{q}_s^k T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\varepsilon_{jk}(\bar{q}_s^k u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j\sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu} u_t)$		

Examples of 4ψ flavor invariants

$$(\bar{q}q)(\bar{q}q): \begin{cases} \mathcal{O}(1): & (\bar{q}_i q^i)(\bar{q}_j q^j), \quad (\bar{q}_i q^j)(\bar{q}_j q^i) \\ \mathcal{O}(Y_u^2): & (\bar{q}Y_u Y_u^\dagger q)(\bar{q}q), \quad (\bar{q}_i q^j)(Y_u Y_u^\dagger)^i_k(\bar{q}^k q_j) \\ \mathcal{O}(Y_d^2): & (\bar{q}Y_d Y_d^\dagger q)(\bar{q}q), \quad (\bar{q}_i q^j)(Y_d Y_d^\dagger)^i_k(\bar{q}^k q_j) \end{cases}$$

$$(\bar{u}u)(\bar{u}u): \begin{cases} \mathcal{O}(1): & (\bar{u}_i u^i)(\bar{u}_j u^j), \quad (\bar{u}_i u^j)(\bar{u}_j u^i) \\ \mathcal{O}(Y_u^2): & (\bar{u}Y_u^\dagger Y_u u)(\bar{u}u), \quad (\bar{u}_i u^j)(Y_u^\dagger Y_u)^i_k(\bar{u}_j u^k) \end{cases}$$

$$(\bar{d}d)(\bar{d}d): \begin{cases} \mathcal{O}(1): & (\bar{d}_i d^i)(\bar{d}_j d^j), \quad (\bar{d}_i d^j)(\bar{d}_j d^i) \\ \mathcal{O}(Y_d^2): & (\bar{d}Y_d^\dagger Y_d d)(\bar{d}d), \quad (\bar{d}_i d^j)(Y_d^\dagger Y_d)^i_k(\bar{d}_j d^k) \end{cases}$$

Greljo, AP, Thomsen [2203.09561]

Flavor counting

MFV$_Q$		$\mathcal{O}(1)$	$\mathcal{O}(Y_u)$	$\mathcal{O}(Y_u^2)$	$\mathcal{O}(Y_d)$	$\mathcal{O}(Y_d^2)$	$\mathcal{O}(Y_uY_d)$	$\mathcal{O}(Y_u^2Y_d, Y_d^2Y_u)$	$\mathcal{O}(Y_u^3, Y_d^3)$
ψ^2H^3	Q_{uH}		1 1					1 1	1 1
	Q_{dH}				1 1			1 1	1 1
ψ^2XH	$Q_{u(G,W,B)}$		3 3					3 3	3 3
	$Q_{d(G,W,B)}$				3 3			3 3	3 3
ψ^2H^2D	$Q_{Hq}^{(1,3)}$	2		2		2			
	Q_{Hu}	1		1					
	Q_{Hd}	1				1			
	Q_{Hud}						1 1		
$(LL)(LL)$	$Q_{qq}^{(1,3)}$	4		4		4			
$(RR)(RR)$	Q_{uu}	2		2					
	Q_{dd}	2				2			
	$Q_{ud}^{(1,8)}$	2		2		2			
$(LL)(RR)$	$Q_{qu}^{(1,8)}$	2		6		2			
	$Q_{qd}^{(1,8)}$	2		2		6			
$(LR)(LR)$	$Q_{quqd}^{(1,8)}$						4 4		
Total		18	4 4	19	4 4	19	5 5	8 8	8 8

Greljo, AP, Thomsen [2203.09561]

Flavor counting

SMEFT dim-6 operator class

MFV$_Q$		$\mathcal{O}(1)$	$\mathcal{O}(Y_u)$	$\mathcal{O}(Y_u^2)$	$\mathcal{O}(Y_d)$	$\mathcal{O}(Y_d^2)$	$\mathcal{O}(Y_uY_d)$	$\mathcal{O}(Y_u^2Y_d, Y_d^2Y_u)$	$\mathcal{O}(Y_u^3, Y_d^3)$
ψ^2H^3	Q_{uH}		1 1					1 1	1 1
	Q_{dH}				1 1			1 1	1 1
ψ^2XH	$Q_{u(G,W,B)}$		3 3					3 3	3 3
	$Q_{d(G,W,B)}$				3 3			3 3	3 3
ψ^2H^2D	$Q_{Hq}^{(1,3)}$	2		2		2			
	Q_{Hu}	1		1					
	Q_{Hd}	1				1			
	Q_{Hud}						1 1		
$(LL)(LL)$	$Q_{qq}^{(1,3)}$	4		4		4			
$(RR)(RR)$	Q_{uu}	2		2					
	Q_{dd}	2				2			
	$Q_{ud}^{(1,8)}$	2		2		2			
$(LL)(RR)$	$Q_{qu}^{(1,8)}$	2		6		2			
	$Q_{qd}^{(1,8)}$	2		2		6			
$(LR)(LR)$	$Q_{quqd}^{(1,8)}$						4 4		
Total		18	4 4	19	4 4	19	5 5	8 8	8 8

Greljo, AP, Thomsen [2203.09561]

Flavor counting

Orders in spurion insertions

SMEFT dim-6 operator class

MFV$_Q$		$\mathcal{O}(1)$	$\mathcal{O}(Y_u)$	$\mathcal{O}(Y_u^2)$	$\mathcal{O}(Y_d)$	$\mathcal{O}(Y_d^2)$	$\mathcal{O}(Y_uY_d)$	$\mathcal{O}(Y_u^2Y_d, Y_d^2Y_u)$	$\mathcal{O}(Y_u^3, Y_d^3)$
ψ^2H^3	Q_{uH}		1 1					1 1	1 1
	Q_{dH}				1 1			1 1	1 1
ψ^2XH	$Q_{u(G,W,B)}$		3 3					3 3	3 3
	$Q_{d(G,W,B)}$				3 3			3 3	3 3
ψ^2H^2D	$Q_{Hq}^{(1,3)}$	2		2		2			
	Q_{Hu}	1		1					
	Q_{Hd}	1				1			
	Q_{Hud}						1 1		
$(LL)(LL)$	$Q_{qq}^{(1,3)}$	4		4		4			
$(RR)(RR)$	Q_{uu}	2		2					
	Q_{dd}	2				2			
	$Q_{ud}^{(1,8)}$	2		2		2			
$(LL)(RR)$	$Q_{qu}^{(1,8)}$	2		6		2			
	$Q_{qd}^{(1,8)}$	2		2		6			
$(LR)(LR)$	$Q_{quqd}^{(1,8)}$						4 4		
Total		18	4 4	19	4 4	19	5 5	8 8	8 8

Greljo, AP, Thomsen [2203.09561]

Flavor counting

Orders in spurion insertions

SMEFT dim-6 operator class

MFV$_Q$		$\mathcal{O}(1)$	$\mathcal{O}(Y_u)$	$\mathcal{O}(Y_u^2)$	$\mathcal{O}(Y_d)$	$\mathcal{O}(Y_d^2)$	$\mathcal{O}(Y_uY_d)$	$\mathcal{O}(Y_u^2Y_d, Y_d^2Y_u)$	$\mathcal{O}(Y_u^3, Y_d^3)$
ψ^2H^3	Q_{uH}		1 1					1 1	1 1
	Q_{dH}				1 1			1 1	1 1
ψ^2XH	$Q_{u(G,W,B)}$		3 3					3 3	3 3
	$Q_{d(G,W,B)}$				3 3			3 3	3 3
ψ^2H^2D	$Q_{Hq}^{(1,3)}$	2		2		2			
	Q_{Hu}	1		1					
	Q_{Hd}	1				1			
	Q_{Hud}						1 1		
$(LL)(LL)$	$Q_{qq}^{(1,3)}$	4		4		4			
$(RR)(RR)$	Q_{uu}	2		2					
	Q_{dd}	2				2			
	$Q_{ud}^{(1,8)}$	2		2		2			
$(LL)(RR)$	$Q_{qu}^{(1,8)}$	2		6		2			
	$Q_{qd}^{(1,8)}$	2		2		6			
$(LR)(LR)$	$Q_{quqd}^{(1,8)}$						4 4		
Total		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

Greljo, AP, Thomsen [2203.09561]

Flavor counting: full $\mathcal{O}(1)$ result

- Repeating the similar exercise both for quark and lepton sector

SMEFT $\mathcal{O}(1)$ terms (dim-6, $\Delta B = 0$)		Lepton sector															
		MFV_L		$\mathrm{U}(3)_V$		$\mathrm{U}(2)^2 \times \mathrm{U}(1)^2$		$\mathrm{U}(2)^2$		$\mathrm{U}(2)_V$		$\mathrm{U}(1)^6$		$\mathrm{U}(1)^3$		No symm.	
Quark sector	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
	$\mathrm{U}(2)^2 \times \mathrm{U}(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
	$\mathrm{U}(2)^3$	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

Greljo, AP, Thomsen [2203.09561]

Flavor counting: full $\mathcal{O}(1)$ result

- Repeating the similar exercise both for quark and lepton sector

SMEFT $\mathcal{O}(1)$ terms (dim-6, $\Delta B = 0$)		Lepton sector															
		MFV_L		$\mathrm{U}(3)_V$		$\mathrm{U}(2)^2 \times \mathrm{U}(1)^2$		$\mathrm{U}(2)^2$		$\mathrm{U}(2)_V$		$\mathrm{U}(1)^6$		$\mathrm{U}(1)^3$		No symm.	
Quark sector	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
	$\mathrm{U}(2)^2 \times \mathrm{U}(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
	$\mathrm{U}(2)^3$	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]

Flavor counting: full $\mathcal{O}(1)$ result

- Repeating the similar exercise both for quark and lepton sector

SMEFT $\mathcal{O}(1)$ terms (dim-6, $\Delta B = 0$)		Lepton sector															
		MFV_L		$\mathrm{U}(3)_V$		$\mathrm{U}(2)^2 \times \mathrm{U}(1)^2$		$\mathrm{U}(2)^2$		$\mathrm{U}(2)_V$		$\mathrm{U}(1)^6$		$\mathrm{U}(1)^3$		No symm.	
Quark sector	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
	$\mathrm{U}(2)^2 \times \mathrm{U}(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
	$\mathrm{U}(2)^3$	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

147 parameters in $U(2)^5$

Faroughy, Isidori, Wilsch, Yamamoto [2005.05366]

Greljo, AP, Thomsen [2203.09561]

Flavor counting: full $\mathcal{O}(1)$ result

- Repeating the similar exercise both for quark and lepton sector

SMEFT $\mathcal{O}(1)$ terms (dim-6, $\Delta B = 0$)		Lepton sector															
		MFV_L		$\mathrm{U}(3)_V$		$\mathrm{U}(2)^2 \times \mathrm{U}(1)^2$		$\mathrm{U}(2)^2$		$\mathrm{U}(2)_V$		$\mathrm{U}(1)^6$		$\mathrm{U}(1)^3$		No symm.	
Quark sector	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
	$\mathrm{U}(2)^2 \times \mathrm{U}(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
	$\mathrm{U}(2)^3$	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

147 parameters in $U(2)^5$

Faroughy, Isidori, Wilsch, Yamamoto [2005.05366]

2499 parameters without any symmetries

Greljo, AP, Thomsen [2203.09561]

Leading directions in the SMEFT

Leading directions: MFV basis

SMEFT $\mathcal{O}(1)$ terms (dim-6, $\Delta B = 0$)		Lepton sector															
		MFV_L		$\text{U}(3)_V$		$\text{U}(2)^2\times\text{U}(1)^2$		$\text{U}(2)^2$		$\text{U}(2)_V$		$\text{U}(1)^6$		$\text{U}(1)^3$		No symm.	
Quark sector	MFV_Q	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
	$\text{U}(2)^2\times\text{U}(3)_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
	$\text{U}(2)^3\times\text{U}(1)_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
	$\text{U}(2)^3$	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

Class	Label	Operator	Label	Operator
$(\bar{L}L)(\bar{L}L)$	$\mathcal{O}_{\ell\ell}^{D}$	$(\bar{\ell}_i\gamma^\mu\ell^i)(\bar{\ell}_j\gamma_\mu\ell^j)$	$\mathcal{O}_{\ell q}^{(1)}$	$(\bar{\ell}_i\gamma^\mu\ell^i)(\bar{q}_j\gamma_\mu q^j)$
	$\mathcal{O}_{\ell\ell}^{E}$	$(\bar{\ell}_i\gamma^\mu\ell^j)(\bar{\ell}_j\gamma_\mu\ell^i)$	$\mathcal{O}_{\ell q}^{(3)}$	$(\bar{\ell}_i\gamma^\mu\sigma^a\ell^i)(\bar{q}_j\gamma_\mu\sigma^a q^j)$
	$\mathcal{O}_{qq}^{(1)D}$	$(\bar{q}_i\gamma^\mu q^i)(\bar{q}_j\gamma_\mu q^j)$	$\mathcal{O}_{qq}^{(3)D}$	$(\bar{q}_i\gamma^\mu\sigma^a q^i)(\bar{q}_j\gamma_\mu\sigma^a q^j)$
	$\mathcal{O}_{qq}^{(1)E}$	$(\bar{q}_i\gamma^\mu q^j)(\bar{q}_j\gamma_\mu q^i)$	$\mathcal{O}_{qq}^{(3)E}$	$(\bar{q}_i\gamma^\mu\sigma^a q^j)(\bar{q}_j\gamma_\mu\sigma^a q^i)$
$(\bar{R}R)(\bar{R}R)$	$\mathcal{O}_{ee}$	$(\bar{e}_i\gamma^\mu e^i)(\bar{e}_j\gamma_\mu e^j)$	$\mathcal{O}_{dd}^{D}$	$(\bar{d}_i\gamma^\mu d^i)(\bar{d}_j\gamma_\mu d^j)$
	$\mathcal{O}_{uu}^{D}$	$(\bar{u}_i\gamma^\mu u^i)(\bar{u}_j\gamma_\mu u^j)$	$\mathcal{O}_{dd}^{E}$	$(\bar{d}_i\gamma^\mu d^j)(\bar{d}_j\gamma_\mu d^i)$
	$\mathcal{O}_{uu}^{E}$	$(\bar{u}_i\gamma^\mu u^j)(\bar{u}_j\gamma_\mu u^i)$	$\mathcal{O}_{ud}^{(1)}$	$(\bar{u}_i\gamma^\mu u^i)(\bar{d}_j\gamma_\mu d^j)$
	$\mathcal{O}_{eu}$	$(\bar{e}_i\gamma^\mu e^i)(\bar{u}_j\gamma_\mu u^j)$	$\mathcal{O}_{ud}^{(8)}$	$(\bar{u}_i\gamma^\mu T^A u^i)(\bar{d}_j\gamma_\mu T^A d^j)$
	$\mathcal{O}_{ed}$	$(\bar{e}_i\gamma^\mu e^i)(\bar{d}_j\gamma_\mu d^j)$		
$(\bar{L}L)(\bar{R}R)$	$\mathcal{O}_{\ell e}$	$(\bar{\ell}_i\gamma^\mu\ell^i)(\bar{e}_j\gamma_\mu e^j)$	$\mathcal{O}_{qu}^{(1)}$	$(\bar{q}_i\gamma^\mu q^i)(\bar{u}_j\gamma_\mu u^j)$
	$\mathcal{O}_{qe}$	$(\bar{q}_i\gamma^\mu q^i)(\bar{e}_j\gamma_\mu e^j)$	$\mathcal{O}_{qu}^{(8)}$	$(\bar{q}_i\gamma^\mu T^A q^i)(\bar{u}_j\gamma_\mu T^A u^j)$
	$\mathcal{O}_{\ell u}$	$(\bar{\ell}_i\gamma^\mu\ell^i)(\bar{u}_j\gamma_\mu u^j)$	$\mathcal{O}_{qd}^{(1)}$	$(\bar{q}_i\gamma^\mu q^i)(\bar{d}_j\gamma_\mu d^j)$
	$\mathcal{O}_{\ell d}$	$(\bar{\ell}_i\gamma^\mu\ell^i)(\bar{d}_j\gamma_\mu d^j)$	$\mathcal{O}_{qd}^{(8)}$	$(\bar{q}_i\gamma^\mu T^A q^i)(\bar{d}_j\gamma_\mu T^A d^j)$
$\psi^2\phi^2 D$	$\mathcal{O}_{\phi\ell}^{(1)}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{\ell}_i\gamma^\mu\ell^i)$	$\mathcal{O}_{\phi e}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{e}_i\gamma^\mu e^i)$
	$\mathcal{O}_{\phi\ell}^{(3)}$	$(\phi^\dagger i\overleftrightarrow{D}^a_\mu\phi)(\bar{\ell}_i\gamma^\mu\sigma^a\ell^i)$	$\mathcal{O}_{\phi u}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{u}_i\gamma^\mu u^i)$
	$\mathcal{O}_{\phi q}^{(1)}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{q}_i\gamma^\mu q^i)$	$\mathcal{O}_{\phi d}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{d}_i\gamma^\mu d^i)$
	$\mathcal{O}_{\phi q}^{(3)}$	$(\phi^\dagger i\overleftrightarrow{D}^a_\mu\phi)(\bar{q}_i\gamma^\mu\sigma^a q^i)$		

Class	Label	Operator	Label	Operator
X^3 Loop generated	$\mathcal{O}_W$	$\varepsilon_{abc}W_\mu^{a\,\nu}W_\nu^{b\,\rho}W_\rho^{c\,\mu}$	$\mathcal{O}_G$	$f_{ABC}G_\mu^{A\,\nu}G_\nu^{B\,\rho}G_\rho^{C\,\mu}$
	$\mathcal{O}_{\tilde{W}}$	$\varepsilon_{abc}\tilde{W}_\mu^{a\,\nu}W_\nu^{b\,\rho}W_\rho^{c\,\mu}$	$\mathcal{O}_{\tilde{G}}$	$f_{ABC}\tilde{G}_\mu^{A\,\nu}G_\nu^{B\,\rho}G_\rho^{C\,\mu}$
ϕ^6	$\mathcal{O}_\phi$	$(\phi^\dagger\phi)^3$		
$\phi^4 D^2$	$\mathcal{O}_{\phi\Box}$	$(\phi^\dagger\phi)\Box(\phi^\dagger\phi)$	$\mathcal{O}_{\phi D}$	$(\phi^\dagger D_\mu\phi)[(D^\mu\phi)^\dagger\phi]$
$X^2\phi^2$ Loop generated	$\mathcal{O}_{\phi B}$	$(\phi^\dagger\phi)B_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{\phi WB}$	$(\phi^\dagger\sigma^a\phi)W_{\mu\nu}^aB^{\mu\nu}$
	$\mathcal{O}_{\phi\tilde{B}}$	$(\phi^\dagger\phi)\tilde{B}_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}B}$	$(\phi^\dagger\sigma^a\phi)\tilde{W}_{\mu\nu}^aB^{\mu\nu}$
	$\mathcal{O}_{\phi W}$	$(\phi^\dagger\phi)W_{\mu\nu}^aW^{a\,\mu\nu}$	$\mathcal{O}_{\phi G}$	$(\phi^\dagger\phi)G_{\mu\nu}^AG^{A\,\mu\nu}$
	$\mathcal{O}_{\phi\tilde{W}}$	$(\phi^\dagger\phi)\tilde{W}_{\mu\nu}^aW^{a\,\mu\nu}$	$\mathcal{O}_{\phi\tilde{G}}$	$(\phi^\dagger\phi)\tilde{G}_{\mu\nu}^AG^{A\,\mu\nu}$

Class	Label	Operator	Label	Operator
$\psi^2\phi^3$	$[\mathcal{O}_{e\phi}]_{i_\ell}^{j_e}$	$(\phi^\dagger\phi)(\bar{\ell}_{i_\ell}\phi e^{j_e})$		
	$[\mathcal{O}_{d\phi}]_{i_q}^{j_d}$	$(\phi^\dagger\phi)(\bar{q}_{i_q}\phi d^{j_d})$	$[\mathcal{O}_{u\phi}]_{i_q}^{j_u}$	$(\phi^\dagger\phi)(\bar{q}_{i_q}\tilde{\phi}u^{j_u})$
$\psi^2 X\phi$ Loop generated	$[\mathcal{O}_{eB}]_{i_\ell}^{j_e}$	$(\bar{\ell}_{i_\ell}\sigma^{\mu\nu}e^{j_e})\phi B_{\mu\nu}$	$[\mathcal{O}_{eW}]_{i_\ell}^{j_e}$	$(\bar{\ell}_{i_\ell}\sigma^{\mu\nu}e^{j_e})\sigma^a\phi W_{\mu\nu}^a$
	$[\mathcal{O}_{uB}]_{i_q}^{j_u}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}u^{j_u})\tilde{\phi}B_{\mu\nu}$	$[\mathcal{O}_{uW}]_{i_q}^{j_u}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}u^{j_u})\sigma^a\tilde{\phi}W_{\mu\nu}^a$
	$[\mathcal{O}_{dB}]_{i_q}^{j_d}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}d^{j_d})\phi B_{\mu\nu}$	$[\mathcal{O}_{dW}]_{i_q}^{j_d}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}d^{j_d})\sigma^a\phi W_{\mu\nu}^a$
	$[\mathcal{O}_{uG}]_{i_q}^{j_u}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}T^Au^{j_u})\tilde{\phi}G_{\mu\nu}^A$	$[\mathcal{O}_{dG}]_{i_q}^{j_d}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}T^Ad^{j_d})\phi G_{\mu\nu}^A$

Greljo, AP [2305.08898]

Leading directions: MFV basis

SMEFT $\mathcal{O}(1)$ terms (dim-6, $\Delta B = 0$)		Lepton sector															
		MFV$_L$		U(3)$_V$		U(2)$^2\times$U(1)^2		U(2)^2		U(2)$_V$		U(1)^6		U(1)^3		No symm.	
Quark sector	MFV$_Q$	41	6	45	9	59	6	62	9	67	13	81	6	93	18	207	132
	U(2)$^2\times$U(3)$_d$	72	10	78	15	95	10	100	15	107	21	122	10	140	28	281	169
	U(2)$^3\times$U(1)$_{d_3}$	86	10	92	15	111	10	116	12	123	21	140	10	158	28	305	175
	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

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

Class	Label	Operator	Label	Operator
$(\bar{L}L)(\bar{L}L)$	$\mathcal{O}_{\ell\ell}^{D}$	$(\bar{\ell}_i\gamma^\mu\ell^i)(\bar{\ell}_j\gamma_\mu\ell^j)$	$\mathcal{O}_{\ell q}^{(1)}$	$(\bar{\ell}_i\gamma^\mu\ell^i)(\bar{q}_j\gamma_\mu q^j)$
	$\mathcal{O}_{\ell\ell}^{E}$	$(\bar{\ell}_i\gamma^\mu\ell^j)(\bar{\ell}_j\gamma_\mu\ell^i)$	$\mathcal{O}_{\ell q}^{(3)}$	$(\bar{\ell}_i\gamma^\mu\sigma^a\ell^i)(\bar{q}_j\gamma_\mu\sigma^a q^j)$
	$\mathcal{O}_{qq}^{(1)D}$	$(\bar{q}_i\gamma^\mu q^i)(\bar{q}_j\gamma_\mu q^j)$	$\mathcal{O}_{qq}^{(3)D}$	$(\bar{q}_i\gamma^\mu\sigma^a q^i)(\bar{q}_j\gamma_\mu\sigma^a q^j)$
	$\mathcal{O}_{qq}^{(1)E}$	$(\bar{q}_i\gamma^\mu q^j)(\bar{q}_j\gamma_\mu q^i)$	$\mathcal{O}_{qq}^{(3)E}$	$(\bar{q}_i\gamma^\mu\sigma^a q^j)(\bar{q}_j\gamma_\mu\sigma^a q^i)$
$(\bar{R}R)(\bar{R}R)$	$\mathcal{O}_{ee}$	$(\bar{e}_i\gamma^\mu e^i)(\bar{e}_j\gamma_\mu e^j)$	$\mathcal{O}_{dd}^{D}$	$(\bar{d}_i\gamma^\mu d^i)(\bar{d}_j\gamma_\mu d^j)$
	$\mathcal{O}_{uu}^{D}$	$(\bar{u}_i\gamma^\mu u^i)(\bar{u}_j\gamma_\mu u^j)$	$\mathcal{O}_{dd}^{E}$	$(\bar{d}_i\gamma^\mu d^j)(\bar{d}_j\gamma_\mu d^i)$
	$\mathcal{O}_{uu}^{E}$	$(\bar{u}_i\gamma^\mu u^j)(\bar{u}_j\gamma_\mu u^i)$	$\mathcal{O}_{ud}^{(1)}$	$(\bar{u}_i\gamma^\mu u^i)(\bar{d}_j\gamma_\mu d^j)$
	$\mathcal{O}_{eu}$	$(\bar{e}_i\gamma^\mu e^i)(\bar{u}_j\gamma_\mu u^j)$	$\mathcal{O}_{ud}^{(8)}$	$(\bar{u}_i\gamma^\mu T^A u^i)(\bar{d}_j\gamma_\mu T^A d^j)$
	$\mathcal{O}_{ed}$	$(\bar{e}_i\gamma^\mu e^i)(\bar{d}_j\gamma_\mu d^j)$		
$(\bar{L}L)(\bar{R}R)$	$\mathcal{O}_{\ell e}$	$(\bar{\ell}_i\gamma^\mu\ell^i)(\bar{e}_j\gamma_\mu e^j)$	$\mathcal{O}_{qu}^{(1)}$	$(\bar{q}_i\gamma^\mu q^i)(\bar{u}_j\gamma_\mu u^j)$
	$\mathcal{O}_{qe}$	$(\bar{q}_i\gamma^\mu q^i)(\bar{e}_j\gamma_\mu e^j)$	$\mathcal{O}_{qu}^{(8)}$	$(\bar{q}_i\gamma^\mu T^A q^i)(\bar{u}_j\gamma_\mu T^A u^j)$
	$\mathcal{O}_{\ell u}$	$(\bar{\ell}_i\gamma^\mu\ell^i)(\bar{u}_j\gamma_\mu u^j)$	$\mathcal{O}_{qd}^{(1)}$	$(\bar{q}_i\gamma^\mu q^i)(\bar{d}_j\gamma_\mu d^j)$
	$\mathcal{O}_{\ell d}$	$(\bar{\ell}_i\gamma^\mu\ell^i)(\bar{d}_j\gamma_\mu d^j)$	$\mathcal{O}_{qd}^{(8)}$	$(\bar{q}_i\gamma^\mu T^A q^i)(\bar{d}_j\gamma_\mu T^A d^j)$
$\psi^2\phi^2 D$	$\mathcal{O}_{\phi\ell}^{(1)}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{\ell}_i\gamma^\mu\ell^i)$	$\mathcal{O}_{\phi e}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{e}_i\gamma^\mu e^i)$
	$\mathcal{O}_{\phi\ell}^{(3)}$	$(\phi^\dagger i\overleftrightarrow{D}^a_\mu\phi)(\bar{\ell}_i\gamma^\mu\sigma^a\ell^i)$	$\mathcal{O}_{\phi u}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{u}_i\gamma^\mu u^i)$
	$\mathcal{O}_{\phi q}^{(1)}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{q}_i\gamma^\mu q^i)$	$\mathcal{O}_{\phi d}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{d}_i\gamma^\mu d^i)$
	$\mathcal{O}_{\phi q}^{(3)}$	$(\phi^\dagger i\overleftrightarrow{D}^a_\mu\phi)(\bar{q}_i\gamma^\mu\sigma^a q^i)$		

Class	Label	Operator	Label	Operator
X^3 Loop generated	$\mathcal{O}_W$	$\varepsilon_{abc}W_\mu^{a\,\nu}W_\nu^{b\,\rho}W_\rho^{c\,\mu}$	$\mathcal{O}_G$	$f_{ABC}G_\mu^{A\,\nu}G_\nu^{B\,\rho}G_\rho^{C\,\mu}$
	$\mathcal{O}_{\tilde{W}}$	$\varepsilon_{abc}\tilde{W}_\mu^{a\,\nu}W_\nu^{b\,\rho}W_\rho^{c\,\mu}$	$\mathcal{O}_{\tilde{G}}$	$f_{ABC}\tilde{G}_\mu^{A\,\nu}G_\nu^{B\,\rho}G_\rho^{C\,\mu}$
ϕ^6	$\mathcal{O}_\phi$	$(\phi^\dagger\phi)^3$		
$\phi^4 D^2$	$\mathcal{O}_{\phi\Box}$	$(\phi^\dagger\phi)\Box(\phi^\dagger\phi)$	$\mathcal{O}_{\phi D}$	$(\phi^\dagger D_\mu\phi)[(D^\mu\phi)^\dagger\phi]$
$X^2\phi^2$ Loop generated	$\mathcal{O}_{\phi B}$	$(\phi^\dagger\phi)B_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{\phi WB}$	$(\phi^\dagger\sigma^a\phi)W_{\mu\nu}^a B^{\mu\nu}$
	$\mathcal{O}_{\phi\tilde{B}}$	$(\phi^\dagger\phi)\tilde{B}_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}B}$	$(\phi^\dagger\sigma^a\phi)\tilde{W}_{\mu\nu}^a B^{\mu\nu}$
	$\mathcal{O}_{\phi W}$	$(\phi^\dagger\phi)W_{\mu\nu}^a W^{a\,\mu\nu}$	$\mathcal{O}_{\phi G}$	$(\phi^\dagger\phi)G_{\mu\nu}^A G^{A\,\mu\nu}$
	$\mathcal{O}_{\phi\tilde{W}}$	$(\phi^\dagger\phi)\tilde{W}_{\mu\nu}^a W^{a\,\mu\nu}$	$\mathcal{O}_{\phi\tilde{G}}$	$(\phi^\dagger\phi)\tilde{G}_{\mu\nu}^A G^{A\,\mu\nu}$

Class	Label	Operator	Label	Operator
$\psi^2\phi^3$	$[\mathcal{O}_{e\phi}]_{i_\ell}^{j_e}$	$(\phi^\dagger\phi)(\bar{\ell}_{i_\ell}\phi e^{j_e})$		
	$[\mathcal{O}_{d\phi}]_{i_q}^{j_d}$	$(\phi^\dagger\phi)(\bar{q}_{i_q}\phi d^{j_d})$	$[\mathcal{O}_{u\phi}]_{i_q}^{j_u}$	$(\phi^\dagger\phi)(\bar{q}_{i_q}\tilde{\phi}u^{j_u})$
$\psi^2 X\phi$ Loop generated	$[\mathcal{O}_{eB}]_{i_\ell}^{j_e}$	$(\bar{\ell}_{i_\ell}\sigma^{\mu\nu}e^{j_e})\phi B_{\mu\nu}$	$[\mathcal{O}_{eW}]_{i_\ell}^{j_e}$	$(\bar{\ell}_{i_\ell}\sigma^{\mu\nu}e^{j_e})\sigma^a\phi W_{\mu\nu}^a$
	$[\mathcal{O}_{uB}]_{i_q}^{j_u}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}u^{j_u})\tilde{\phi}B_{\mu\nu}$	$[\mathcal{O}_{uW}]_{i_q}^{j_u}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}u^{j_u})\sigma^a\tilde{\phi}W_{\mu\nu}^a$
	$[\mathcal{O}_{dB}]_{i_q}^{j_d}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}d^{j_d})\phi B_{\mu\nu}$	$[\mathcal{O}_{dW}]_{i_q}^{j_d}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}d^{j_d})\sigma^a\phi W_{\mu\nu}^a$
	$[\mathcal{O}_{uG}]_{i_q}^{j_u}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}T^A u^{j_u})\tilde{\phi}G_{\mu\nu}^A$	$[\mathcal{O}_{dG}]_{i_q}^{j_d}$	$(\bar{q}_{i_q}\sigma^{\mu\nu}T^A d^{j_d})\phi G_{\mu\nu}^A$

Greljo, AP [2305.08898]

Leading directions: SM + 1 NP

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

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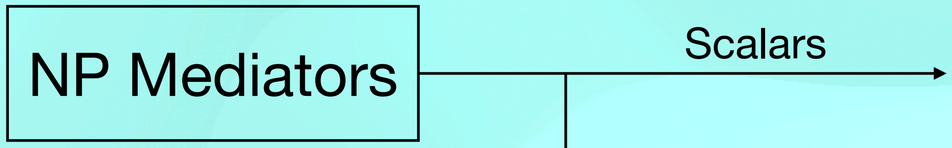


Scalars

$\mathcal{S}$	$\mathcal{S}_1$	$\mathcal{S}_2$	φ	Ξ	Ξ_1	Θ_1	Θ_3
$(1,1)_0$	$(1,1)_1$	$(1,1)_2$	$(1,2)_{\frac{1}{2}}$	$(1,3)_0$	$(1,3)_1$	$(1,4)_{\frac{1}{2}}$	$(1,4)_{\frac{3}{2}}$
ω_1	ω_2	ω_4	Π_1	Π_7	ζ		
$(3,1)_{-\frac{1}{3}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{-\frac{4}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{\frac{7}{6}}$	$(3,3)_{-\frac{1}{3}}$		
Ω_1	Ω_2	Ω_4	Υ	Φ			
$(6,1)_{\frac{1}{3}}$	$(6,1)_{-\frac{2}{3}}$	$(6,1)_{\frac{4}{3}}$	$(6,3)_{\frac{1}{3}}$	$(8,2)_{\frac{1}{2}}$			

Fermions

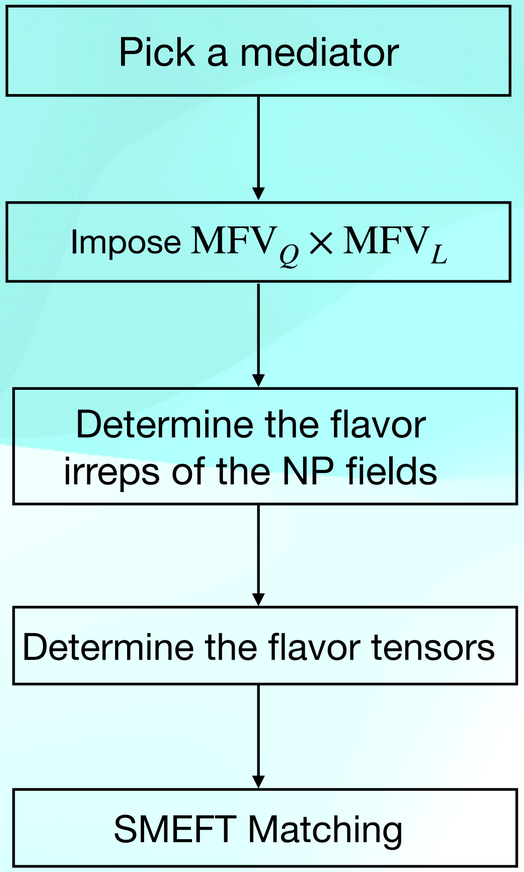
N	E	Δ_1	Δ_3	Σ	Σ_1	
$(1,1)_0$	$(1,1)_{-1}$	$(1,2)_{-\frac{1}{2}}$	$(1,2)_{-\frac{3}{2}}$	$(1,3)_0$	$(1,3)_{-1}$	
U	D	Q_1	Q_5	Q_7	T_1	T_2
$(3,1)_{\frac{2}{3}}$	$(3,1)_{-\frac{1}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,2)_{\frac{7}{6}}$	$(3,3)_{-\frac{1}{3}}$	$(3,3)_{\frac{2}{3}}$

Vectors

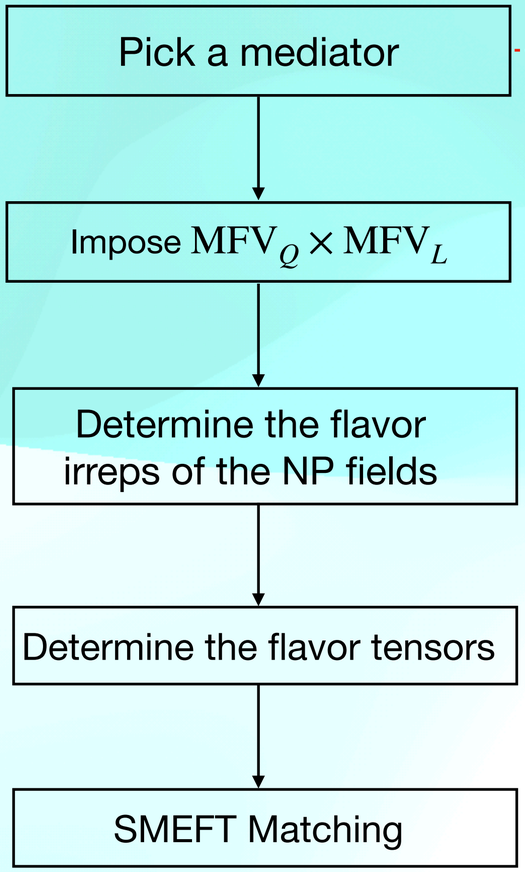
$\mathcal{B}$	$\mathcal{B}_1$	$\mathcal{W}$	$\mathcal{W}_1$	$\mathcal{G}$	$\mathcal{G}_1$	$\mathcal{H}$	$\mathcal{L}_1$
$(1,1)_0$	$(1,1)_1$	$(1,3)_0$	$(1,3)_1$	$(8,1)_0$	$(8,1)_1$	$(8,3)_0$	$(1,2)_{\frac{1}{2}}$
$\mathcal{L}_3$	$\mathcal{U}_2$	$\mathcal{U}_5$	$\mathcal{Q}_1$	$\mathcal{Q}_5$	$\mathcal{X}$	$\mathcal{Y}_1$	$\mathcal{Y}_5$
$(1,2)_{-\frac{3}{2}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,3)_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

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

Leading directions: Procedure and example

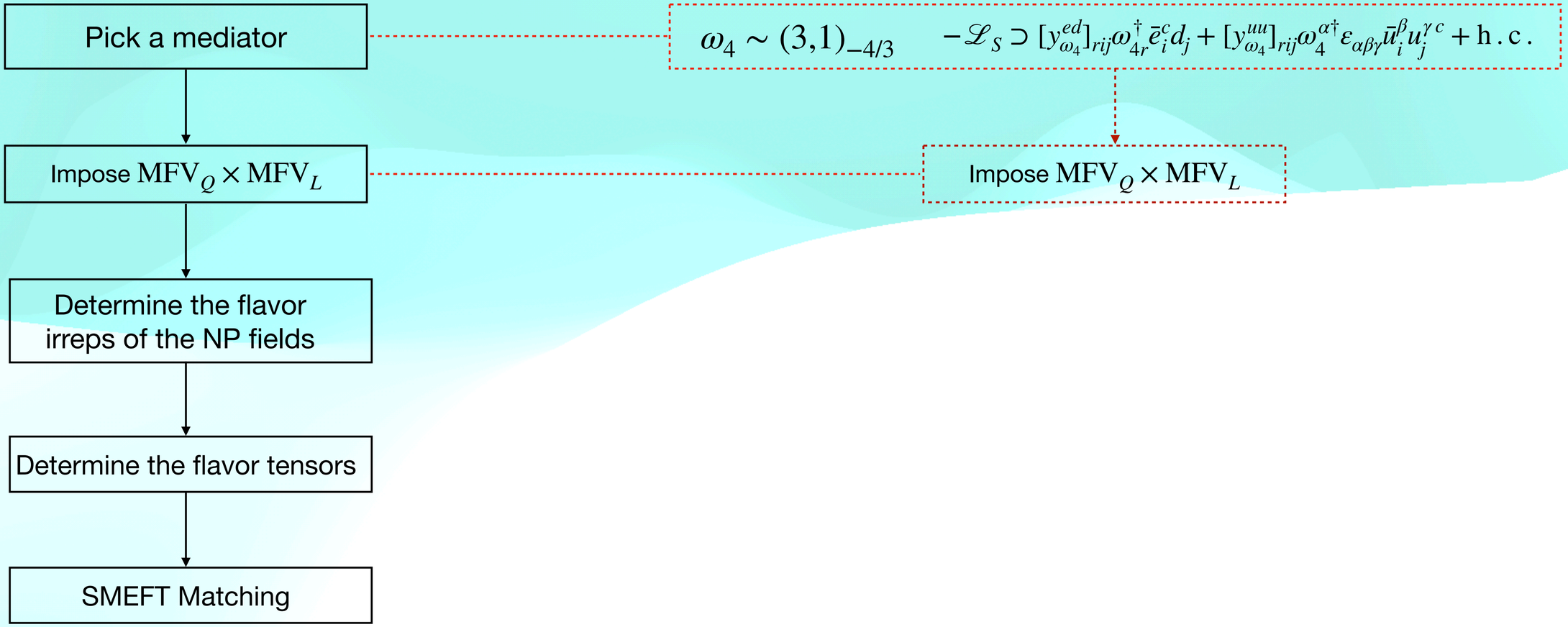


Leading directions: Procedure and example

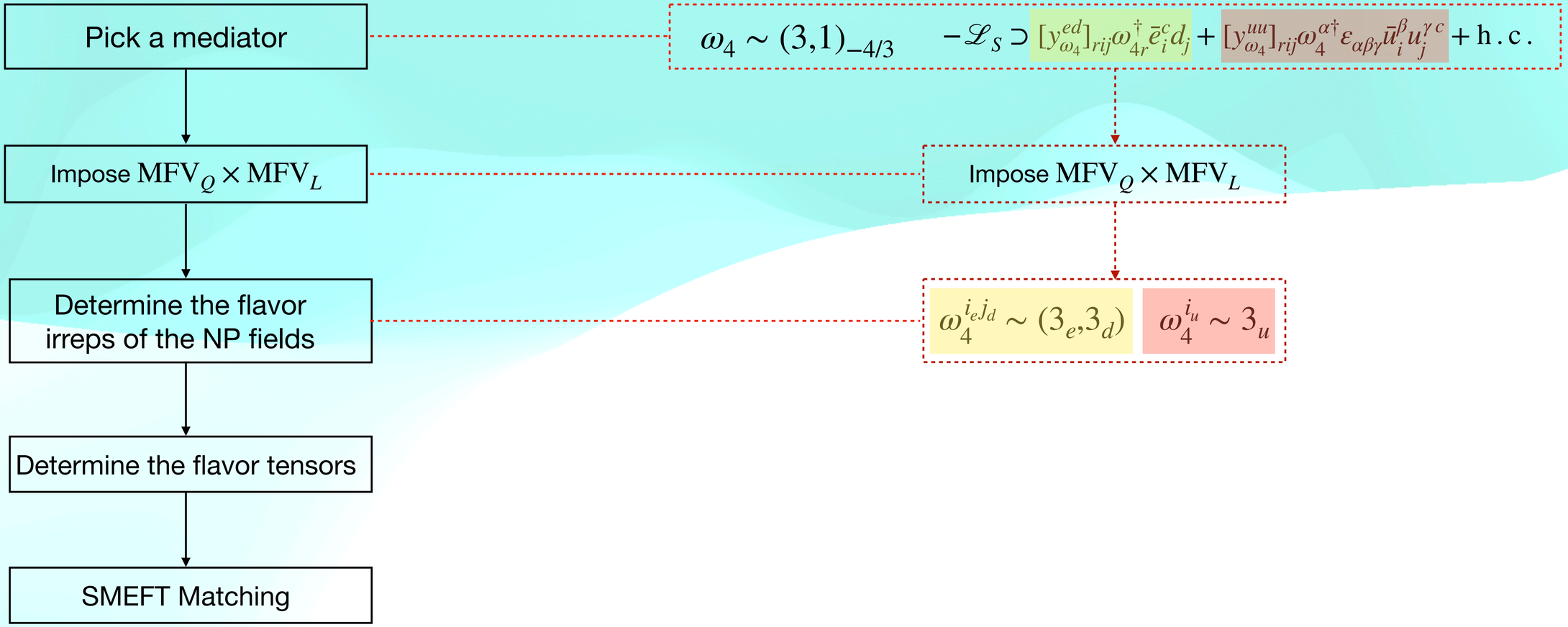


$\omega_4 \sim (3,1)_{-4/3}$ $\quad -\mathscr{L}_S \supset [y^{ed}_{\omega_4}]_{rij}\omega^{\dagger}_{4r}\bar{e}^c_i d_j + [y^{uu}_{\omega_4}]_{rij}\omega^{\alpha\dagger}_4 \varepsilon_{\alpha\beta\gamma}\bar{u}^{\beta}_i u^{\gamma\, c}_j + \mathrm{h.c.}$

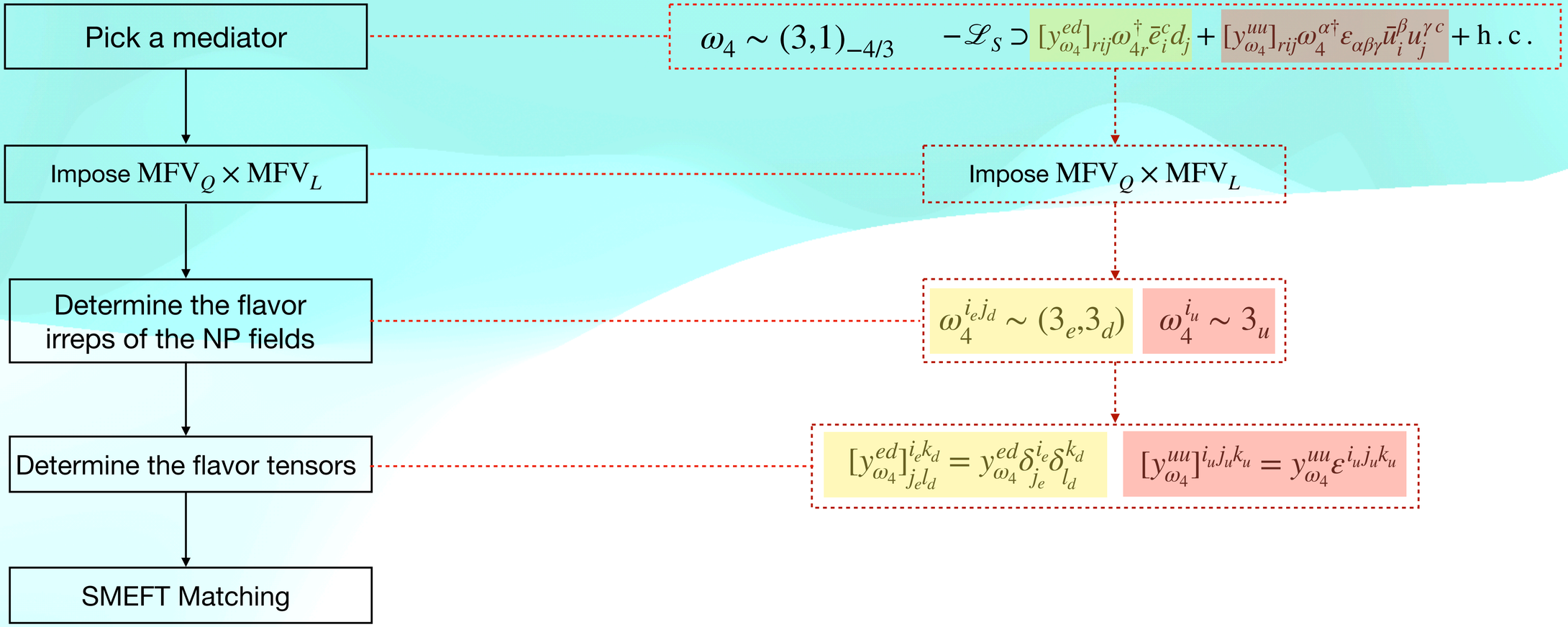
Leading directions: Procedure and example



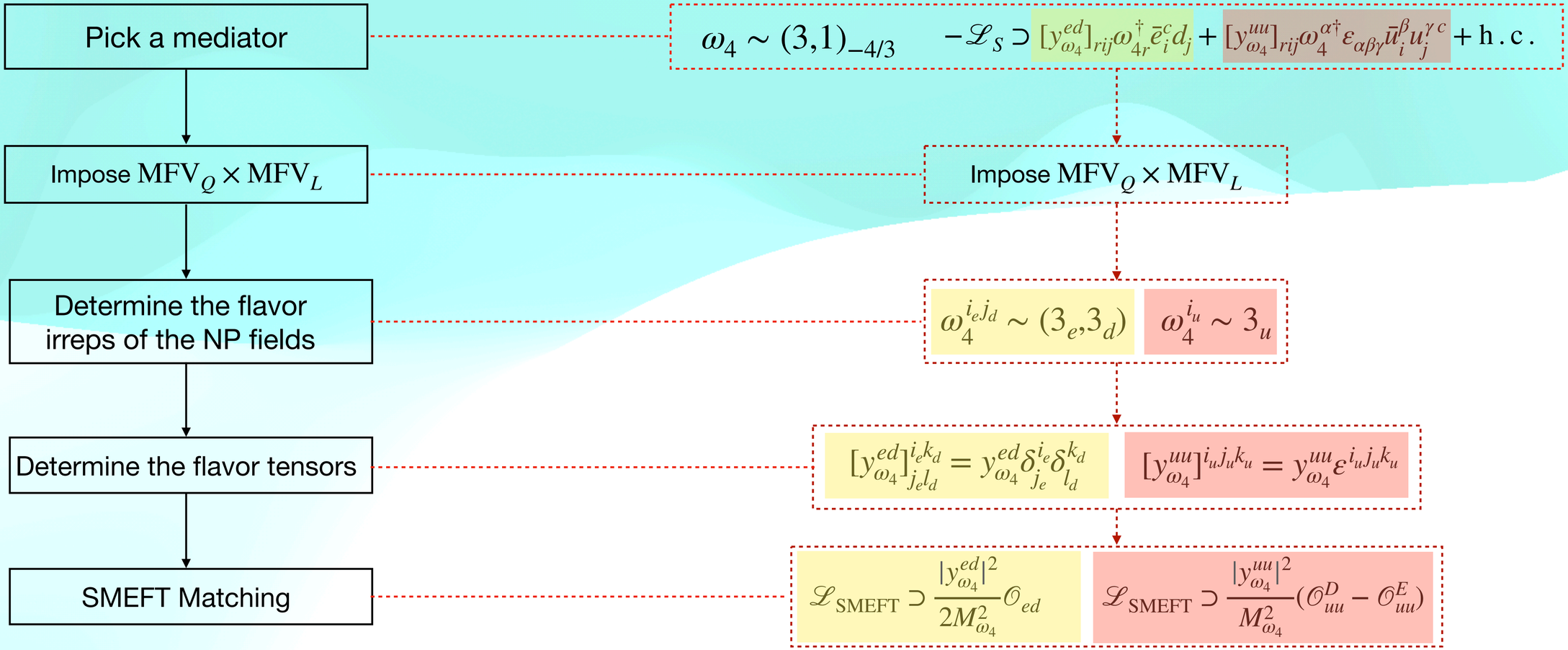
Leading directions: Procedure and example



Leading directions: Procedure and example



Leading directions: Procedure and example



Greljo, AP [2305.08898]

Leading directions: Results

Field	Irrep	Normalization	Operator
$\mathcal{S}_1 \sim (\mathbf{1},\mathbf{1})_1$	$\mathbf{3}_\ell$	$\lvert y_{\mathcal{S}_1}\rvert^2/M^2_{\mathcal{S}_1}$	$\mathcal{O}^D_{\ell\ell} - \mathcal{O}^E_{\ell\ell}$
$\mathcal{S}_2 \sim (\mathbf{1},\mathbf{1})_2$	$\bar{\mathbf{6}}_e$	$\lvert y_{\mathcal{S}_2}\rvert^2/(2M^2_{\mathcal{S}_2})$	$\mathcal{O}_{ee}$
$\varphi \sim (\mathbf{1},\mathbf{2})_{\frac{1}{2}}$	$(\bar{\mathbf{3}}_e,\mathbf{3}_\ell)$	$-\lvert y^e_\varphi\rvert^2/(2M^2_\varphi)$	$\mathcal{O}_{\ell e}$
	$(\bar{\mathbf{3}}_d,\mathbf{3}_q)$	$-\lvert y^d_\varphi\rvert^2/(6M^2_\varphi)$	$\mathcal{O}^{(1)}_{qd} + 6\mathcal{O}^{(8)}_{qd}$
	$(\bar{\mathbf{3}}_q,\mathbf{3}_u)$	$-\lvert y^u_\varphi\rvert^2/(6M^2_\varphi)$	$\mathcal{O}^{(1)}_{qu} + 6\mathcal{O}^{(8)}_{qu}$
$\Xi_1 \sim (\mathbf{1},\mathbf{3})_1$	$\bar{\mathbf{6}}_\ell$	$\lvert y_{\Xi_1}\rvert^2/(2M^2_{\Xi_1})$	$\mathcal{O}^D_{\ell\ell} + \mathcal{O}^E_{\ell\ell}$
$\omega_1 \sim (\mathbf{3},\mathbf{1})_{-\frac{1}{3}}$	$(\mathbf{3}_q,\mathbf{3}_\ell)$	$\lvert y^{q\ell}_{\omega_1}\rvert^2/(4M^2_{\omega_1})$	$\mathcal{O}^{(1)}_{\ell q} - \mathcal{O}^{(3)}_{\ell q}$
	$(\mathbf{3}_e,\mathbf{3}_u)$	$\lvert y^{eu}_{\omega_1}\rvert^2/(2M^2_{\omega_1})$	$\mathcal{O}_{eu}$
	$\bar{\mathbf{6}}_q$	$\lvert y^{qq}_{\omega_1}\rvert^2/(4M^2_{\omega_1})$	$\mathcal{O}^{(1)D}_{qq} - \mathcal{O}^{(3)D}_{qq} + \mathcal{O}^{(1)E}_{qq} - \mathcal{O}^{(3)E}_{qq}$
	$(\bar{\mathbf{3}}_d,\bar{\mathbf{3}}_u)$	$\lvert y^{du}_{\omega_1}\rvert^2/(3M^2_{\omega_1})$	$\mathcal{O}^{(1)}_{ud} - 3\mathcal{O}^{(8)}_{ud}$
$\omega_2 \sim (\mathbf{3},\mathbf{1})_{\frac{2}{3}}$	$\mathbf{3}_d$	$\lvert y_{\omega_2}\rvert^2/M^2_{\omega_2}$	$\mathcal{O}^D_{dd} - \mathcal{O}^E_{dd}$
$\omega_4 \sim (\mathbf{3},\mathbf{1})_{-\frac{4}{3}}$	$(\mathbf{3}_e,\mathbf{3}_d)$	$\lvert y^{ed}_{\omega_4}\rvert^2/(2M^2_{\omega_4})$	$\mathcal{O}_{ed}$
	$\mathbf{3}_u$	$\lvert y^{uu}_{\omega_4}\rvert^2/M^2_{\omega_4}$	$\mathcal{O}^D_{uu} - \mathcal{O}^E_{uu}$
$\Pi_1 \sim (\mathbf{3},\mathbf{2})_{\frac{1}{6}}$	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_d)$	$-\lvert y_{\Pi_1}\rvert^2/(2M^2_{\Pi_1})$	$\mathcal{O}_{\ell d}$
$\Pi_7 \sim (\mathbf{3},\mathbf{2})_{\frac{7}{6}}$	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_u)$	$-\left\lvert y^{\ell u}_{\Pi_7}\right\rvert^2/(2M^2_{\Pi_7})$	$\mathcal{O}_{\ell u}$
	$(\bar{\mathbf{3}}_e,\mathbf{3}_q)$	$-\lvert y^{qe}_{\Pi_7}\rvert^2/(2M^2_{\Pi_7})$	$\mathcal{O}_{qe}$
$\zeta \sim (\mathbf{3},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{3}_q,\mathbf{3}_\ell)$	$\lvert y^{q\ell}_\zeta\rvert^2/(4M^2_\zeta)$	$3\mathcal{O}^{(1)}_{\ell q} + \mathcal{O}^{(3)}_{\ell q}$
	$\mathbf{3}_q$	$\lvert y^{qq}_\zeta\rvert^2/(2M^2_\zeta)$	$3\mathcal{O}^{(1)D}_{qq} + \mathcal{O}^{(3)D}_{qq} - 3\mathcal{O}^{(1)E}_{qq} - \mathcal{O}^{(3)E}_{qq}$
$\Omega_1 \sim (\mathbf{6},\mathbf{1})_{\frac{1}{3}}$	$(\mathbf{3}_u,\mathbf{3}_d)$	$\lvert y^{ud}_{\Omega_1}\rvert^2/(6M^2_{\Omega_1})$	$2\mathcal{O}^{(1)}_{ud} + 3\mathcal{O}^{(8)}_{ud}$
	$\bar{\mathbf{3}}_q$	$\lvert y^{qq}_{\Omega_1}\rvert^2/(4M^2_{\Omega_1})$	$\mathcal{O}^{(1)D}_{qq} - \mathcal{O}^{(3)D}_{qq} - \mathcal{O}^{(1)E}_{qq} + \mathcal{O}^{(3)E}_{qq}$
$\Omega_2 \sim (\mathbf{6},\mathbf{1})_{-\frac{2}{3}}$	$\mathbf{6}_d$	$\lvert y_{\Omega_2}\rvert^2/(4M^2_{\Omega_2})$	$\mathcal{O}^D_{dd} + \mathcal{O}^E_{dd}$
$\Omega_4 \sim (\mathbf{6},\mathbf{1})_{\frac{4}{3}}$	$\mathbf{6}_u$	$\lvert y_{\Omega_4}\rvert^2/(4M^2_{\Omega_4})$	$\mathcal{O}^D_{uu} + \mathcal{O}^E_{uu}$
$\Upsilon \sim (\mathbf{6},\mathbf{3})_{\frac{1}{3}}$	$\mathbf{6}_q$	$\lvert y_\Upsilon\rvert^2/(8M^2_\Upsilon)$	$3\mathcal{O}^{(1)D}_{qq} + \mathcal{O}^{(3)D}_{qq} + 3\mathcal{O}^{(1)E}_{qq} + \mathcal{O}^{(3)E}_{qq}$
$\Phi \sim (\mathbf{8},\mathbf{2})_{\frac{1}{2}}$	$(\bar{\mathbf{3}}_q,\mathbf{3}_u)$	$-\lvert y^{qu}_\Phi\rvert^2/(18M^2_\Phi)$	$4\mathcal{O}^{(1)}_{qu} - 3\mathcal{O}^{(8)}_{qu}$
	$(\bar{\mathbf{3}}_d,\mathbf{3}_q)$	$-\lvert y^{dq}_\Phi\rvert^2/(18M^2_\Phi)$	$4\mathcal{O}^{(1)}_{qd} - 3\mathcal{O}^{(8)}_{qd}$

Field	Irrep	Normalization	Operator
$\mathcal{B} \sim (\mathbf{1},\mathbf{1})_0$	$\mathbf{8}_\ell$	$-(g^\ell_\mathcal{B})^2/(12M^2_\mathcal{B})$	$3\mathcal{O}^E_{\ell\ell} - \mathcal{O}^D_{\ell\ell}$
	$\mathbf{8}_e$	$-(g^e_\mathcal{B})^2/(6M^2_\mathcal{B})$	$\mathcal{O}_{ee}$
	$\mathbf{8}_q$	$-(g^q_\mathcal{B})^2/(12M^2_\mathcal{B})$	$3\mathcal{O}^{(1)E}_{qq} - \mathcal{O}^{(1)D}_{qq}$
	$\mathbf{8}_u$	$-(g^u_\mathcal{B})^2/(12M^2_\mathcal{B})$	$3\mathcal{O}^E_{uu} - \mathcal{O}^D_{uu}$
	$\mathbf{8}_d$	$-(g^d_\mathcal{B})^2/(12M^2_\mathcal{B})$	$3\mathcal{O}^E_{dd} - \mathcal{O}^D_{dd}$
$\mathcal{B}_1 \sim (\mathbf{1},\mathbf{1})_1$	$(\bar{\mathbf{3}}_d,\mathbf{3}_u)$	$-\lvert g^{du}_{\mathcal{B}_1}\rvert^2/(3M^2_{\mathcal{B}_1})$	$\mathcal{O}^{(1)}_{ud} + 6\mathcal{O}^{(8)}_{ud}$
$\mathcal{W} \sim (\mathbf{1},\mathbf{3})_0$	$\mathbf{8}_q$	$-(g^q_\mathcal{W})^2/(48M^2_\mathcal{W})$	$3\mathcal{O}^{(3)E}_{qq} - \mathcal{O}^{(3)D}_{qq}$
	$\mathbf{8}_\ell$	$(g^\ell_\mathcal{W})^2/(48M^2_\mathcal{W})$	$5\mathcal{O}^E_{\ell\ell} - 7\mathcal{O}^D_{\ell\ell}$
$\mathcal{L}_3 \sim (\mathbf{1},\mathbf{2})_{-\frac{3}{2}}$	$(\mathbf{3}_e,\mathbf{3}_\ell)$	$\lvert g_{\mathcal{L}_3}\rvert^2/M^2_{\mathcal{L}_3}$	$\mathcal{O}_{\ell e}$
$\mathcal{U}_2 \sim (\mathbf{3},\mathbf{1})_{\frac{2}{3}}$	$(\bar{\mathbf{3}}_e,\mathbf{3}_d)$	$-\lvert g^{ed}_{\mathcal{U}_2}\rvert^2/M^2_{\mathcal{U}_2}$	$\mathcal{O}_{ed}$
	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_q)$	$-\lvert g^{\ell q}_{\mathcal{U}_2}\rvert^2/(2M^2_{\mathcal{U}_2})$	$\mathcal{O}^{(1)}_{\ell q} + \mathcal{O}^{(3)}_{\ell q}$
$\mathcal{U}_5 \sim (\mathbf{3},\mathbf{1})_{\frac{5}{3}}$	$(\bar{\mathbf{3}}_e,\mathbf{3}_u)$	$-\lvert g_{\mathcal{U}_5}\rvert^2/M^2_{\mathcal{U}_5}$	$\mathcal{O}_{eu}$
$\mathcal{Q}_1 \sim (\mathbf{3},\mathbf{2})_{\frac{1}{6}}$	$(\mathbf{3}_u,\mathbf{3}_\ell)$	$\lvert g^{u\ell}_{\mathcal{Q}_1}\rvert^2/M^2_{\mathcal{Q}_1}$	$\mathcal{O}_{\ell u}$
	$(\bar{\mathbf{3}}_d,\bar{\mathbf{3}}_q)$	$2\lvert g^{dq}_{\mathcal{Q}_1}\rvert^2/(3M^2_{\mathcal{Q}_1})$	$\mathcal{O}^{(1)}_{qd} - 3\mathcal{O}^{(8)}_{qd}$
$\mathcal{Q}_5 \sim (\mathbf{3},\mathbf{2})_{-\frac{5}{6}}$	$(\mathbf{3}_d,\mathbf{3}_\ell)$	$\lvert g^{d\ell}_{\mathcal{Q}_5}\rvert^2/M^2_{\mathcal{Q}_5}$	$\mathcal{O}_{\ell d}$
	$(\mathbf{3}_e,\mathbf{3}_q)$	$\lvert g^{eq}_{\mathcal{Q}_5}\rvert^2/M^2_{\mathcal{Q}_5}$	$\mathcal{O}_{qe}$
	$(\bar{\mathbf{3}}_u,\bar{\mathbf{3}}_q)$	$2\lvert g^{uq}_{\mathcal{Q}_5}\rvert^2/(3M^2_{\mathcal{Q}_5})$	$\mathcal{O}^{(1)}_{qu} - 3\mathcal{O}^{(8)}_{qu}$
$\mathcal{X} \sim (\mathbf{3},\mathbf{3})_{\frac{2}{3}}$	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_q)$	$-\lvert g_\mathcal{X}\rvert^2/(8M^2_\mathcal{X})$	$3\mathcal{O}^{(1)}_{\ell q} - \mathcal{O}^{(3)}_{\ell q}$
$\mathcal{Y}_1 \sim (\bar{\mathbf{6}},\mathbf{2})_{\frac{1}{6}}$	$(\bar{\mathbf{3}}_d,\bar{\mathbf{3}}_q)$	$\lvert g_{\mathcal{Y}_1}\rvert^2/(3M^2_{\mathcal{Y}_1})$	$2\mathcal{O}^{(1)}_{qd} + 3\mathcal{O}^{(8)}_{qd}$
$\mathcal{Y}_5 \sim (\bar{\mathbf{6}},\mathbf{2})_{-\frac{5}{6}}$	$(\bar{\mathbf{3}}_u,\bar{\mathbf{3}}_q)$	$\lvert g_{\mathcal{Y}_5}\rvert^2/(3M^2_{\mathcal{Y}_5})$	$2\mathcal{O}^{(1)}_{qu} + 3\mathcal{O}^{(8)}_{qu}$
$\mathcal{G} \sim (\mathbf{8},\mathbf{1})_0$	$\mathbf{8}_q$	$-(g^q_\mathcal{G})^2/(144M^2_\mathcal{G})$	$11\mathcal{O}^{(1)D}_{qq} - 9\mathcal{O}^{(1)E}_{qq} + 9\mathcal{O}^{(3)D}_{qq} - 3\mathcal{O}^{(3)E}_{qq}$
	$\mathbf{8}_u$	$(g^u_\mathcal{G})^2/(36M^2_\mathcal{G})$	$3\mathcal{O}^E_{uu} - 5\mathcal{O}^D_{uu}$
	$\mathbf{8}_d$	$(g^d_\mathcal{G})^2/(36M^2_\mathcal{G})$	$3\mathcal{O}^E_{dd} - 5\mathcal{O}^D_{dd}$
$\mathcal{G}_1 \sim (\mathbf{8},\mathbf{1})_1$	$(\bar{\mathbf{3}}_d,\mathbf{3}_u)$	$\lvert g_{\mathcal{G}_1}\rvert^2/(9M^2_{\mathcal{G}_1})$	$-4\mathcal{O}^{(1)}_{ud} + 3\mathcal{O}^{(8)}_{ud}$
$\mathcal{H} \sim (\mathbf{8},\mathbf{3})_0$	$\mathbf{8}_q$	$-(g_\mathcal{H})^2/(576M^2_\mathcal{H})$	$27\mathcal{O}^{(1)D}_{qq} - 9\mathcal{O}^{(1)E}_{qq} - 7\mathcal{O}^{(3)D}_{qq} - 3\mathcal{O}^{(3)E}_{qq}$

Field	Irrep	Normalization	Operator
$N \sim (\mathbf{1},\mathbf{1})_0$	$\mathbf{3}_\ell$	$\lvert\lambda_N\rvert^2/(4M^2_N)$	$\mathcal{O}^{(1)}_{\phi\ell} - \mathcal{O}^{(3)}_{\phi\ell}$
$E \sim (\mathbf{1},\mathbf{1})_{-1}$	$\mathbf{3}_\ell$	$-\lvert\lambda_E\rvert^2/(4M^2_E)$	$\mathcal{O}^{(1)}_{\phi\ell} + \mathcal{O}^{(3)}_{\phi\ell} - [2y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Delta_1 \sim (\mathbf{1},\mathbf{2})_{-\frac{1}{2}}$	$\mathbf{3}_e$	$\lvert\lambda_{\Delta_1}\rvert^2/(2M^2_{\Delta_1})$	$\mathcal{O}_{\phi e} + [y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Delta_3 \sim (\mathbf{1},\mathbf{2})_{-\frac{3}{2}}$	$\mathbf{3}_e$	$-\lvert\lambda_{\Delta_3}\rvert^2/(2M^2_{\Delta_3})$	$\mathcal{O}_{\phi e} - [y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Sigma \sim (\mathbf{1},\mathbf{3})_0$	$\mathbf{3}_\ell$	$\lvert\lambda_\Sigma\rvert^2/(16M^2_\Sigma)$	$3\mathcal{O}^{(1)}_{\phi\ell} + \mathcal{O}^{(3)}_{\phi\ell} + [4y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Sigma_1 \sim (\mathbf{1},\mathbf{3})_{-1}$	$\mathbf{3}_\ell$	$\lvert\lambda_{\Sigma_1}\rvert^2/(16M^2_{\Sigma_1})$	$\mathcal{O}^{(3)}_{\phi\ell} - 3\mathcal{O}^{(1)}_{\phi\ell} + [2y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$U \sim (\mathbf{3},\mathbf{1})_{\frac{2}{3}}$	$\mathbf{3}_q$	$\lvert\lambda_U\rvert^2/(4M^2_U)$	$\mathcal{O}^{(1)}_{\phi q} - \mathcal{O}^{(3)}_{\phi q} + [2y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
$D \sim (\mathbf{3},\mathbf{1})_{-\frac{1}{3}}$	$\mathbf{3}_q$	$-\lvert\lambda_D\rvert^2/(4M^2_D)$	$\mathcal{O}^{(1)}_{\phi q} + \mathcal{O}^{(3)}_{\phi q} - [2y^*_d\mathcal{O}_{d\phi} + \text{h.c.}]$
$Q_1 \sim (\mathbf{3},\mathbf{2})_{\frac{1}{6}}$	$\mathbf{3}_u$	$-\lvert\lambda^u_{Q_1}\rvert^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi u} - [y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
	$\mathbf{3}_d$	$\lvert\lambda^d_{Q_1}\rvert^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi d} + [y^*_d\mathcal{O}_{d\phi} + \text{h.c.}]$
$Q_5 \sim (\mathbf{3},\mathbf{2})_{-\frac{5}{6}}$	$\mathbf{3}_d$	$-\lvert\lambda_{Q_5}\rvert^2/(2M^2_{Q_5})$	$\mathcal{O}_{\phi d} - [y^*_d\mathcal{O}_{d\phi} + \text{h.c.}]$
$Q_7 \sim (\mathbf{3},\mathbf{2})_{\frac{7}{6}}$	$\mathbf{3}_u$	$\lvert\lambda_{Q_7}\rvert^2/(2M^2_{Q_7})$	$\mathcal{O}_{\phi u} + [y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
$T_1 \sim (\mathbf{3},\mathbf{3})_{-\frac{1}{3}}$	$\mathbf{3}_q$	$\lvert\lambda_{T_1}\rvert^2/(16M^2_{T_1})$	$\mathcal{O}^{(3)}_{\phi q} - 3\mathcal{O}^{(1)}_{\phi q} + [2y^*_d\mathcal{O}_{d\phi} + 4y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
$T_2 \sim (\mathbf{3},\mathbf{3})_{\frac{2}{3}}$	$\mathbf{3}_q$	$\lvert\lambda_{T_2}\rvert^2/(16M^2_{T_2})$	$\mathcal{O}^{(3)}_{\phi q} + 3\mathcal{O}^{(1)}_{\phi q} + [4y^*_d\mathcal{O}_{d\phi} + 2y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$

Leading directions: Results

Field	Irrep	Normalization	Operator
$\mathcal{S}_1 \sim (\mathbf{1},\mathbf{1})_1$	$\mathbf{3}_\ell$	$\lvert y_{\mathcal{S}_1}\rvert^2/M^2_{\mathcal{S}_1}$	$\mathcal{O}^D_{\ell\ell} - \mathcal{O}^E_{\ell\ell}$
$\mathcal{S}_2 \sim (\mathbf{1},\mathbf{1})_2$	$\bar{\mathbf{6}}_e$	$\lvert y_{\mathcal{S}_2}\rvert^2/(2M^2_{\mathcal{S}_2})$	$\mathcal{O}_{ee}$
$\varphi \sim (\mathbf{1},\mathbf{2})_{\frac{1}{2}}$	$(\bar{\mathbf{3}}_e,\mathbf{3}_\ell)$	$-\lvert y^e_\varphi\rvert^2/(2M^2_\varphi)$	$\mathcal{O}_{\ell e}$
	$(\bar{\mathbf{3}}_d,\mathbf{3}_q)$	$-\lvert y^d_\varphi\rvert^2/(6M^2_\varphi)$	$\mathcal{O}^{(1)}_{qd} + 6\mathcal{O}^{(8)}_{qd}$
	$(\bar{\mathbf{3}}_q,\mathbf{3}_u)$	$-\lvert y^u_\varphi\rvert^2/(6M^2_\varphi)$	$\mathcal{O}^{(1)}_{qu} + 6\mathcal{O}^{(8)}_{qu}$
$\Xi_1 \sim (\mathbf{1},\mathbf{3})_1$	$\bar{\mathbf{6}}_\ell$	$\lvert y_{\Xi_1}\rvert^2/(2M^2_{\Xi_1})$	$\mathcal{O}^D_{\ell\ell} + \mathcal{O}^E_{\ell\ell}$
$\omega_1 \sim (\mathbf{3},\mathbf{1})_{-\frac{1}{3}}$	$(\mathbf{3}_q,\mathbf{3}_\ell)$	$\lvert y^{q\ell}_{\omega_1}\rvert^2/(4M^2_{\omega_1})$	$\mathcal{O}^{(1)}_{\ell q} - \mathcal{O}^{(3)}_{\ell q}$
	$(\mathbf{3}_e,\mathbf{3}_u)$	$\lvert y^{eu}_{\omega_1}\rvert^2/(2M^2_{\omega_1})$	$\mathcal{O}_{eu}$
	$\bar{\mathbf{6}}_q$	$\lvert y^{qq}_{\omega_1}\rvert^2/(4M^2_{\omega_1})$	$\mathcal{O}^{(1)D}_{qq} - \mathcal{O}^{(3)D}_{qq} + \mathcal{O}^{(1)E}_{qq} - \mathcal{O}^{(3)E}_{qq}$
	$(\bar{\mathbf{3}}_d,\bar{\mathbf{3}}_u)$	$\lvert y^{du}_{\omega_1}\rvert^2/(3M^2_{\omega_1})$	$\mathcal{O}^{(1)}_{ud} - 3\mathcal{O}^{(8)}_{ud}$
$\omega_2 \sim (\mathbf{3},\mathbf{1})_{\frac{2}{3}}$	$\mathbf{3}_d$	$\lvert y_{\omega_2}\rvert^2/M^2_{\omega_2}$	$\mathcal{O}^D_{dd} - \mathcal{O}^E_{dd}$
$\omega_4 \sim (\mathbf{3},\mathbf{1})_{-\frac{4}{3}}$	$(\mathbf{3}_e,\mathbf{3}_d)$	$\lvert y^{ed}_{\omega_4}\rvert^2/(2M^2_{\omega_4})$	$\mathcal{O}_{ed}$
	$\mathbf{3}_u$	$\lvert y^{uu}_{\omega_4}\rvert^2/M^2_{\omega_4}$	$\mathcal{O}^D_{uu} - \mathcal{O}^E_{uu}$
$\Pi_1 \sim (\mathbf{3},\mathbf{2})_{\frac{1}{6}}$	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_d)$	$-\lvert y_{\Pi_1}\rvert^2/(2M^2_{\Pi_1})$	$\mathcal{O}_{\ell d}$
$\Pi_7 \sim (\mathbf{3},\mathbf{2})_{\frac{7}{6}}$	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_u)$	$-\lvert y^{\ell u}_{\Pi_7}\rvert^2/(2M^2_{\Pi_7})$	$\mathcal{O}_{\ell u}$
	$(\bar{\mathbf{3}}_e,\mathbf{3}_q)$	$-\lvert y^{qe}_{\Pi_7}\rvert^2/(2M^2_{\Pi_7})$	$\mathcal{O}_{qe}$
$\zeta \sim (\mathbf{3},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{3}_q,\mathbf{3}_\ell)$	$\lvert y^{q\ell}_\zeta\rvert^2/(4M^2_\zeta)$	$3\mathcal{O}^{(1)}_{\ell q} + \mathcal{O}^{(3)}_{\ell q}$
	$\mathbf{3}_q$	$\lvert y^{qq}_\zeta\rvert^2/(2M^2_\zeta)$	$3\mathcal{O}^{(1)D}_{qq} + \mathcal{O}^{(3)D}_{qq} - 3\mathcal{O}^{(1)E}_{qq} - \mathcal{O}^{(3)E}_{qq}$
$\Omega_1 \sim (\mathbf{6},\mathbf{1})_{\frac{1}{3}}$	$(\mathbf{3}_u,\mathbf{3}_d)$	$\lvert y^{ud}_{\Omega_1}\rvert^2/(6M^2_{\Omega_1})$	$2\mathcal{O}^{(1)}_{ud} + 3\mathcal{O}^{(8)}_{ud}$
	$\bar{\mathbf{3}}_q$	$\lvert y^{qq}_{\Omega_1}\rvert^2/(4M^2_{\Omega_1})$	$\mathcal{O}^{(1)D}_{qq} - \mathcal{O}^{(3)D}_{qq} - \mathcal{O}^{(1)E}_{qq} + \mathcal{O}^{(3)E}_{qq}$
$\Omega_2 \sim (\mathbf{6},\mathbf{1})_{-\frac{2}{3}}$	$\mathbf{6}_d$	$\lvert y_{\Omega_2}\rvert^2/(4M^2_{\Omega_2})$	$\mathcal{O}^D_{dd} + \mathcal{O}^E_{dd}$
$\Omega_4 \sim (\mathbf{6},\mathbf{1})_{\frac{4}{3}}$	$\mathbf{6}_u$	$\lvert y_{\Omega_4}\rvert^2/(4M^2_{\Omega_4})$	$\mathcal{O}^D_{uu} + \mathcal{O}^E_{uu}$
$\Upsilon \sim (\mathbf{6},\mathbf{3})_{\frac{1}{3}}$	$\mathbf{6}_q$	$\lvert y_\Upsilon\rvert^2/(8M^2_\Upsilon)$	$3\mathcal{O}^{(1)D}_{qq} + \mathcal{O}^{(3)D}_{qq} + 3\mathcal{O}^{(1)E}_{qq} + \mathcal{O}^{(3)E}_{qq}$
$\Phi \sim (\mathbf{8},\mathbf{2})_{\frac{1}{2}}$	$(\bar{\mathbf{3}}_q,\mathbf{3}_u)$	$-\lvert y^{qu}_\Phi\rvert^2/(18M^2_\Phi)$	$4\mathcal{O}^{(1)}_{qu} - 3\mathcal{O}^{(8)}_{qu}$
	$(\bar{\mathbf{3}}_d,\mathbf{3}_q)$	$-\lvert y^{dq}_\Phi\rvert^2/(18M^2_\Phi)$	$4\mathcal{O}^{(1)}_{qd} - 3\mathcal{O}^{(8)}_{qd}$

Field	Irrep	Normalization	Operator
$\mathcal{B} \sim (\mathbf{1},\mathbf{1})_0$	$\mathbf{8}_\ell$	$-(g^\ell_{\mathcal{B}})^2/(12M^2_{\mathcal{B}})$	$3\mathcal{O}^E_{\ell\ell} - \mathcal{O}^D_{\ell\ell}$
	$\mathbf{8}_e$	$-(g^e_{\mathcal{B}})^2/(6M^2_{\mathcal{B}})$	$\mathcal{O}_{ee}$
	$\mathbf{8}_q$	$-(g^q_{\mathcal{B}})^2/(12M^2_{\mathcal{B}})$	$3\mathcal{O}^{(1)E}_{qq} - \mathcal{O}^{(1)D}_{qq}$
	$\mathbf{8}_u$	$-(g^u_{\mathcal{B}})^2/(12M^2_{\mathcal{B}})$	$3\mathcal{O}^E_{uu} - \mathcal{O}^D_{uu}$
	$\mathbf{8}_d$	$-(g^d_{\mathcal{B}})^2/(12M^2_{\mathcal{B}})$	$3\mathcal{O}^E_{dd} - \mathcal{O}^D_{dd}$
$\mathcal{B}_1 \sim (\mathbf{1},\mathbf{1})_1$	$(\bar{\mathbf{3}}_d,\mathbf{3}_u)$	$-\lvert g^{du}_{\mathcal{B}_1}\rvert^2/(3M^2_{\mathcal{B}_1})$	$\mathcal{O}^{(1)}_{ud} + 6\mathcal{O}^{(8)}_{ud}$
$\mathcal{W} \sim (\mathbf{1},\mathbf{3})_0$	$\mathbf{8}_q$	$-(g^q_{\mathcal{W}})^2/(48M^2_{\mathcal{W}})$	$3\mathcal{O}^{(3)E}_{qq} - \mathcal{O}^{(3)D}_{qq}$
	$\mathbf{8}_\ell$	$(g^\ell_{\mathcal{W}})^2/(48M^2_{\mathcal{W}})$	$5\mathcal{O}^E_{\ell\ell} - 7\mathcal{O}^D_{\ell\ell}$
$\mathcal{L}_3 \sim (\mathbf{1},\mathbf{2})_{-\frac{3}{2}}$	$(\mathbf{3}_e,\mathbf{3}_\ell)$	$\lvert g_{\mathcal{L}_3}\rvert^2/M^2_{\mathcal{L}_3}$	$\mathcal{O}_{\ell e}$
$\mathcal{U}_2 \sim (\mathbf{3},\mathbf{1})_{\frac{2}{3}}$	$(\bar{\mathbf{3}}_e,\mathbf{3}_d)$	$-\lvert g^{ed}_{\mathcal{U}_2}\rvert^2/M^2_{\mathcal{U}_2}$	$\mathcal{O}_{ed}$
	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_q)$	$-\lvert g^{\ell q}_{\mathcal{U}_2}\rvert^2/(2M^2_{\mathcal{U}_2})$	$\mathcal{O}^{(1)}_{\ell q} + \mathcal{O}^{(3)}_{\ell q}$
$\mathcal{U}_5 \sim (\mathbf{3},\mathbf{1})_{\frac{5}{3}}$	$(\bar{\mathbf{3}}_e,\mathbf{3}_u)$	$-\lvert g_{\mathcal{U}_5}\rvert^2/M^2_{\mathcal{U}_5}$	$\mathcal{O}_{eu}$
$\mathcal{Q}_1 \sim (\mathbf{3},\mathbf{2})_{\frac{1}{6}}$	$(\mathbf{3}_u,\mathbf{3}_\ell)$	$\lvert g^{u\ell}_{\mathcal{Q}_1}\rvert^2/M^2_{\mathcal{Q}_1}$	$\mathcal{O}_{\ell u}$
	$(\bar{\mathbf{3}}_d,\bar{\mathbf{3}}_q)$	$2\lvert g^{dq}_{\mathcal{Q}_1}\rvert^2/(3M^2_{\mathcal{Q}_1})$	$\mathcal{O}^{(1)}_{qd} - 3\mathcal{O}^{(8)}_{qd}$
$\mathcal{Q}_5 \sim (\mathbf{3},\mathbf{2})_{-\frac{5}{6}}$	$(\mathbf{3}_d,\mathbf{3}_\ell)$	$\lvert g^{d\ell}_{\mathcal{Q}_5}\rvert^2/M^2_{\mathcal{Q}_5}$	$\mathcal{O}_{\ell d}$
	$(\mathbf{3}_e,\mathbf{3}_q)$	$\lvert g^{eq}_{\mathcal{Q}_5}\rvert^2/M^2_{\mathcal{Q}_5}$	$\mathcal{O}_{qe}$
	$(\bar{\mathbf{3}}_u,\bar{\mathbf{3}}_q)$	$2\lvert g^{uq}_{\mathcal{Q}_5}\rvert^2/(3M^2_{\mathcal{Q}_5})$	$\mathcal{O}^{(1)}_{qu} - 3\mathcal{O}^{(8)}_{qu}$
$\mathcal{X} \sim (\mathbf{3},\mathbf{3})_{\frac{2}{3}}$	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_q)$	$-\lvert g_{\mathcal{X}}\rvert^2/(8M^2_{\mathcal{X}})$	$3\mathcal{O}^{(1)}_{\ell q} - \mathcal{O}^{(3)}_{\ell q}$
$\mathcal{Y}_1 \sim (\bar{\mathbf{6}},\mathbf{2})_{\frac{1}{6}}$	$(\bar{\mathbf{3}}_d,\bar{\mathbf{3}}_q)$	$\lvert g_{\mathcal{Y}_1}\rvert^2/(3M^2_{\mathcal{Y}_1})$	$2\mathcal{O}^{(1)}_{qd} + 3\mathcal{O}^{(8)}_{qd}$
$\mathcal{Y}_5 \sim (\bar{\mathbf{6}},\mathbf{2})_{-\frac{5}{6}}$	$(\bar{\mathbf{3}}_u,\bar{\mathbf{3}}_q)$	$\lvert g_{\mathcal{Y}_5}\rvert^2/(3M^2_{\mathcal{Y}_5})$	$2\mathcal{O}^{(1)}_{qu} + 3\mathcal{O}^{(8)}_{qu}$
$\mathcal{G} \sim (\mathbf{8},\mathbf{1})_0$	$\mathbf{8}_q$	$-(g^q_{\mathcal{G}})^2/(144M^2_{\mathcal{G}})$	$11\mathcal{O}^{(1)D}_{qq} - 9\mathcal{O}^{(1)E}_{qq} + 9\mathcal{O}^{(3)D}_{qq} - 3\mathcal{O}^{(3)E}_{qq}$
	$\mathbf{8}_u$	$(g^u_{\mathcal{G}})^2/(36M^2_{\mathcal{G}})$	$3\mathcal{O}^E_{uu} - 5\mathcal{O}^D_{uu}$
	$\mathbf{8}_d$	$(g^d_{\mathcal{G}})^2/(36M^2_{\mathcal{G}})$	$3\mathcal{O}^E_{dd} - 5\mathcal{O}^D_{dd}$
$\mathcal{G}_1 \sim (\mathbf{8},\mathbf{1})_1$	$(\bar{\mathbf{3}}_d,\mathbf{3}_u)$	$\lvert g_{\mathcal{G}_1}\rvert^2/(9M^2_{\mathcal{G}_1})$	$-4\mathcal{O}^{(1)}_{ud} + 3\mathcal{O}^{(8)}_{ud}$
$\mathcal{H} \sim (\mathbf{8},\mathbf{3})_0$	$\mathbf{8}_q$	$-(g_{\mathcal{H}})^2/(576M^2_{\mathcal{H}})$	$27\mathcal{O}^{(1)D}_{qq} - 9\mathcal{O}^{(1)E}_{qq} - 7\mathcal{O}^{(3)D}_{qq} - 3\mathcal{O}^{(3)E}_{qq}$

Field	Irrep	Normalization	Operator
$N \sim (\mathbf{1},\mathbf{1})_0$	$\mathbf{3}_\ell$	$\lvert\lambda_N\rvert^2/(4M^2_N)$	$\mathcal{O}^{(1)}_{\phi\ell} - \mathcal{O}^{(3)}_{\phi\ell}$
$E \sim (\mathbf{1},\mathbf{1})_{-1}$	$\mathbf{3}_\ell$	$-\lvert\lambda_E\rvert^2/(4M^2_E)$	$\mathcal{O}^{(1)}_{\phi\ell} + \mathcal{O}^{(3)}_{\phi\ell} - [2y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Delta_1 \sim (\mathbf{1},\mathbf{2})_{-\frac{1}{2}}$	$\mathbf{3}_e$	$\lvert\lambda_{\Delta_1}\rvert^2/(2M^2_{\Delta_1})$	$\mathcal{O}_{\phi e} + [y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Delta_3 \sim (\mathbf{1},\mathbf{2})_{-\frac{3}{2}}$	$\mathbf{3}_e$	$-\lvert\lambda_{\Delta_3}\rvert^2/(2M^2_{\Delta_3})$	$\mathcal{O}_{\phi e} - [y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Sigma \sim (\mathbf{1},\mathbf{3})_0$	$\mathbf{3}_\ell$	$\lvert\lambda_\Sigma\rvert^2/(16M^2_\Sigma)$	$3\mathcal{O}^{(1)}_{\phi\ell} + \mathcal{O}^{(3)}_{\phi\ell} + [4y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Sigma_1 \sim (\mathbf{1},\mathbf{3})_{-1}$	$\mathbf{3}_\ell$	$\lvert\lambda_{\Sigma_1}\rvert^2/(16M^2_{\Sigma_1})$	$\mathcal{O}^{(3)}_{\phi\ell} - 3\mathcal{O}^{(1)}_{\phi\ell} + [2y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$U \sim (\mathbf{3},\mathbf{1})_{\frac{2}{3}}$	$\mathbf{3}_q$	$\lvert\lambda_U\rvert^2/(4M^2_U)$	$\mathcal{O}^{(1)}_{\phi q} - \mathcal{O}^{(3)}_{\phi q} + [2y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
$D \sim (\mathbf{3},\mathbf{1})_{-\frac{1}{3}}$	$\mathbf{3}_q$	$-\lvert\lambda_D\rvert^2/(4M^2_D)$	$\mathcal{O}^{(1)}_{\phi q} + \mathcal{O}^{(3)}_{\phi q} - [2y^*_d\mathcal{O}_{d\phi} + \text{h.c.}]$
$Q_1 \sim (\mathbf{3},\mathbf{2})_{\frac{1}{6}}$	$\mathbf{3}_u$	$-\lvert\lambda^u_{Q_1}\rvert^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi u} - [y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
	$\mathbf{3}_d$	$\lvert\lambda^d_{Q_1}\rvert^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi d} + [y^*_d\mathcal{O}_{d\phi} + \text{h.c.}]$
$Q_5 \sim (\mathbf{3},\mathbf{2})_{-\frac{5}{6}}$	$\mathbf{3}_d$	$-\lvert\lambda_{Q_5}\rvert^2/(2M^2_{Q_5})$	$\mathcal{O}_{\phi d} - [y^*_d\mathcal{O}_{d\phi} + \text{h.c.}]$
$Q_7 \sim (\mathbf{3},\mathbf{2})_{\frac{7}{6}}$	$\mathbf{3}_u$	$\lvert\lambda_{Q_7}\rvert^2/(2M^2_{Q_7})$	$\mathcal{O}_{\phi u} + [y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
$T_1 \sim (\mathbf{3},\mathbf{3})_{-\frac{1}{3}}$	$\mathbf{3}_q$	$\lvert\lambda_{T_1}\rvert^2/(16M^2_{T_1})$	$\mathcal{O}^{(3)}_{\phi q} - 3\mathcal{O}^{(1)}_{\phi q} + [2y^*_d\mathcal{O}_{d\phi} + 4y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
$T_2 \sim (\mathbf{3},\mathbf{3})_{\frac{2}{3}}$	$\mathbf{3}_q$	$\lvert\lambda_{T_2}\rvert^2/(16M^2_{T_2})$	$\mathcal{O}^{(3)}_{\phi q} + 3\mathcal{O}^{(1)}_{\phi q} + [4y^*_d\mathcal{O}_{d\phi} + 2y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$

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

Greljo, AP [2305.08898]

Leading directions: Results

Field	Irrep	Normalization	Operator
$\mathcal{S}_1 \sim (\mathbf{1},\mathbf{1})_1$	$\mathbf{3}_\ell$	$\lvert y_{\mathcal{S}_1}\rvert^2/M^2_{\mathcal{S}_1}$	$\mathcal{O}^D_{\ell\ell} - \mathcal{O}^E_{\ell\ell}$
$\mathcal{S}_2 \sim (\mathbf{1},\mathbf{1})_2$	$\bar{\mathbf{6}}_e$	$\lvert y_{\mathcal{S}_2}\rvert^2/(2M^2_{\mathcal{S}_2})$	$\mathcal{O}_{ee}$
$\varphi \sim (\mathbf{1},\mathbf{2})_{\frac{1}{2}}$	$(\bar{\mathbf{3}}_e,\mathbf{3}_\ell)$	$-\lvert y^e_\varphi\rvert^2/(2M^2_\varphi)$	$\mathcal{O}_{\ell e}$
	$(\bar{\mathbf{3}}_d,\mathbf{3}_q)$	$-\lvert y^d_\varphi\rvert^2/(6M^2_\varphi)$	$\mathcal{O}^{(1)}_{qd} + 6\mathcal{O}^{(8)}_{qd}$
	$(\bar{\mathbf{3}}_q,\mathbf{3}_u)$	$-\lvert y^u_\varphi\rvert^2/(6M^2_\varphi)$	$\mathcal{O}^{(1)}_{qu} + 6\mathcal{O}^{(8)}_{qu}$
$\Xi_1 \sim (\mathbf{1},\mathbf{3})_1$	$\bar{\mathbf{6}}_\ell$	$\lvert y_{\Xi_1}\rvert^2/(2M^2_{\Xi_1})$	$\mathcal{O}^D_{\ell\ell} + \mathcal{O}^E_{\ell\ell}$
$\omega_1 \sim (\mathbf{3},\mathbf{1})_{-\frac{1}{3}}$	$(\mathbf{3}_q,\mathbf{3}_\ell)$	$\lvert y^{q\ell}_{\omega_1}\rvert^2/(4M^2_{\omega_1})$	$\mathcal{O}^{(1)}_{\ell q} - \mathcal{O}^{(3)}_{\ell q}$
	$(\mathbf{3}_e,\mathbf{3}_u)$	$\lvert y^{eu}_{\omega_1}\rvert^2/(2M^2_{\omega_1})$	$\mathcal{O}_{eu}$
	$\bar{\mathbf{6}}_q$	$\lvert y^{qq}_{\omega_1}\rvert^2/(4M^2_{\omega_1})$	$\mathcal{O}^{(1)D}_{qq} - \mathcal{O}^{(3)D}_{qq} + \mathcal{O}^{(1)E}_{qq} - \mathcal{O}^{(3)E}_{qq}$
	$(\bar{\mathbf{3}}_d,\bar{\mathbf{3}}_u)$	$\lvert y^{du}_{\omega_1}\rvert^2/(3M^2_{\omega_1})$	$\mathcal{O}^{(1)}_{ud} - 3\mathcal{O}^{(8)}_{ud}$
$\omega_2 \sim (\mathbf{3},\mathbf{1})_{\frac{2}{3}}$	$\mathbf{3}_d$	$\lvert y_{\omega_2}\rvert^2/M^2_{\omega_2}$	$\mathcal{O}^D_{dd} - \mathcal{O}^E_{dd}$
$\omega_4 \sim (\mathbf{3},\mathbf{1})_{-\frac{4}{3}}$	$(\mathbf{3}_e,\mathbf{3}_d)$	$\lvert y^{ed}_{\omega_4}\rvert^2/(2M^2_{\omega_4})$	$\mathcal{O}_{ed}$
	$\mathbf{3}_u$	$\lvert y^{uu}_{\omega_4}\rvert^2/M^2_{\omega_4}$	$\mathcal{O}^D_{uu} - \mathcal{O}^E_{uu}$
$\Pi_1 \sim (\mathbf{3},\mathbf{2})_{\frac{1}{6}}$	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_d)$	$-\lvert y_{\Pi_1}\rvert^2/(2M^2_{\Pi_1})$	$\mathcal{O}_{\ell d}$
$\Pi_7 \sim (\mathbf{3},\mathbf{2})_{\frac{7}{6}}$	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_u)$	$-\lvert y^{\ell u}_{\Pi_7}\rvert^2/(2M^2_{\Pi_7})$	$\mathcal{O}_{\ell u}$
	$(\bar{\mathbf{3}}_e,\mathbf{3}_q)$	$-\lvert y^{qe}_{\Pi_7}\rvert^2/(2M^2_{\Pi_7})$	$\mathcal{O}_{qe}$
$\zeta \sim (\mathbf{3},\mathbf{3})_{-\frac{1}{3}}$	$(\mathbf{3}_q,\mathbf{3}_\ell)$	$\lvert y^{q\ell}_\zeta\rvert^2/(4M^2_\zeta)$	$3\mathcal{O}^{(1)}_{\ell q} + \mathcal{O}^{(3)}_{\ell q}$
	$\mathbf{3}_q$	$\lvert y^{qq}_\zeta\rvert^2/(2M^2_\zeta)$	$3\mathcal{O}^{(1)D}_{qq} + \mathcal{O}^{(3)D}_{qq} - 3\mathcal{O}^{(1)E}_{qq} - \mathcal{O}^{(3)E}_{qq}$
$\Omega_1 \sim (\mathbf{6},\mathbf{1})_{\frac{1}{3}}$	$(\mathbf{3}_u,\mathbf{3}_d)$	$\lvert y^{ud}_{\Omega_1}\rvert^2/(6M^2_{\Omega_1})$	$2\mathcal{O}^{(1)}_{ud} + 3\mathcal{O}^{(8)}_{ud}$
	$\bar{\mathbf{3}}_q$	$\lvert y^{qq}_{\Omega_1}\rvert^2/(4M^2_{\Omega_1})$	$\mathcal{O}^{(1)D}_{qq} - \mathcal{O}^{(3)D}_{qq} - \mathcal{O}^{(1)E}_{qq} + \mathcal{O}^{(3)E}_{qq}$
$\Omega_2 \sim (\mathbf{6},\mathbf{1})_{-\frac{2}{3}}$	$\mathbf{6}_d$	$\lvert y_{\Omega_2}\rvert^2/(4M^2_{\Omega_2})$	$\mathcal{O}^D_{dd} + \mathcal{O}^E_{dd}$
$\Omega_4 \sim (\mathbf{6},\mathbf{1})_{\frac{4}{3}}$	$\mathbf{6}_u$	$\lvert y_{\Omega_4}\rvert^2/(4M^2_{\Omega_4})$	$\mathcal{O}^D_{uu} + \mathcal{O}^E_{uu}$
$\Upsilon \sim (\mathbf{6},\mathbf{3})_{\frac{1}{3}}$	$\mathbf{6}_q$	$\lvert y_\Upsilon\rvert^2/(8M^2_\Upsilon)$	$3\mathcal{O}^{(1)D}_{qq} + \mathcal{O}^{(3)D}_{qq} + 3\mathcal{O}^{(1)E}_{qq} + \mathcal{O}^{(3)E}_{qq}$
$\Phi \sim (\mathbf{8},\mathbf{2})_{\frac{1}{2}}$	$(\bar{\mathbf{3}}_q,\mathbf{3}_u)$	$-\lvert y^{qu}_\Phi\rvert^2/(18M^2_\Phi)$	$4\mathcal{O}^{(1)}_{qu} - 3\mathcal{O}^{(8)}_{qu}$
	$(\bar{\mathbf{3}}_d,\mathbf{3}_q)$	$-\lvert y^{dq}_\Phi\rvert^2/(18M^2_\Phi)$	$4\mathcal{O}^{(1)}_{qd} - 3\mathcal{O}^{(8)}_{qd}$

Field	Irrep	Normalization	Operator
$\mathcal{B} \sim (\mathbf{1},\mathbf{1})_0$	$\mathbf{8}_\ell$	$-(g^\ell_{\mathcal{B}})^2/(12M^2_{\mathcal{B}})$	$3\mathcal{O}^E_{\ell\ell} - \mathcal{O}^D_{\ell\ell}$
	$\mathbf{8}_e$	$-(g^e_{\mathcal{B}})^2/(6M^2_{\mathcal{B}})$	$\mathcal{O}_{ee}$
	$\mathbf{8}_q$	$-(g^q_{\mathcal{B}})^2/(12M^2_{\mathcal{B}})$	$3\mathcal{O}^{(1)E}_{qq} - \mathcal{O}^{(1)D}_{qq}$
	$\mathbf{8}_u$	$-(g^u_{\mathcal{B}})^2/(12M^2_{\mathcal{B}})$	$3\mathcal{O}^E_{uu} - \mathcal{O}^D_{uu}$
	$\mathbf{8}_d$	$-(g^d_{\mathcal{B}})^2/(12M^2_{\mathcal{B}})$	$3\mathcal{O}^E_{dd} - \mathcal{O}^D_{dd}$
$\mathcal{B}_1 \sim (\mathbf{1},\mathbf{1})_1$	$(\bar{\mathbf{3}}_d,\mathbf{3}_u)$	$-\lvert g^{du}_{\mathcal{B}_1}\rvert^2/(3M^2_{\mathcal{B}_1})$	$\mathcal{O}^{(1)}_{ud} + 6\mathcal{O}^{(8)}_{ud}$
$\mathcal{W} \sim (\mathbf{1},\mathbf{3})_0$	$\mathbf{8}_q$	$-(g^q_{\mathcal{W}})^2/(48M^2_{\mathcal{W}})$	$3\mathcal{O}^{(3)E}_{qq} - \mathcal{O}^{(3)D}_{qq}$
	$\mathbf{8}_\ell$	$(g^\ell_{\mathcal{W}})^2/(48M^2_{\mathcal{W}})$	$5\mathcal{O}^E_{\ell\ell} - 7\mathcal{O}^D_{\ell\ell}$
$\mathcal{L}_3 \sim (\mathbf{1},\mathbf{2})_{-\frac{3}{2}}$	$(\mathbf{3}_e,\mathbf{3}_\ell)$	$\lvert g_{\mathcal{L}_3}\rvert^2/M^2_{\mathcal{L}_3}$	$\mathcal{O}_{\ell e}$
$\mathcal{U}_2 \sim (\mathbf{3},\mathbf{1})_{\frac{2}{3}}$	$(\bar{\mathbf{3}}_e,\mathbf{3}_d)$	$-\lvert g^{ed}_{\mathcal{U}_2}\rvert^2/M^2_{\mathcal{U}_2}$	$\mathcal{O}_{ed}$
	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_q)$	$-\lvert g^{\ell q}_{\mathcal{U}_2}\rvert^2/(2M^2_{\mathcal{U}_2})$	$\mathcal{O}^{(1)}_{\ell q} + \mathcal{O}^{(3)}_{\ell q}$
$\mathcal{U}_5 \sim (\mathbf{3},\mathbf{1})_{\frac{5}{3}}$	$(\bar{\mathbf{3}}_e,\mathbf{3}_u)$	$-\lvert g_{\mathcal{U}_5}\rvert^2/M^2_{\mathcal{U}_5}$	$\mathcal{O}_{eu}$
$\mathcal{Q}_1 \sim (\mathbf{3},\mathbf{2})_{\frac{1}{6}}$	$(\mathbf{3}_u,\mathbf{3}_\ell)$	$\lvert g^{u\ell}_{\mathcal{Q}_1}\rvert^2/M^2_{\mathcal{Q}_1}$	$\mathcal{O}_{\ell u}$
	$(\bar{\mathbf{3}}_d,\bar{\mathbf{3}}_q)$	$2\lvert g^{dq}_{\mathcal{Q}_1}\rvert^2/(3M^2_{\mathcal{Q}_1})$	$\mathcal{O}^{(1)}_{qd} - 3\mathcal{O}^{(8)}_{qd}$
$\mathcal{Q}_5 \sim (\mathbf{3},\mathbf{2})_{-\frac{5}{6}}$	$(\mathbf{3}_d,\mathbf{3}_\ell)$	$\lvert g^{d\ell}_{\mathcal{Q}_5}\rvert^2/M^2_{\mathcal{Q}_5}$	$\mathcal{O}_{\ell d}$
	$(\mathbf{3}_e,\mathbf{3}_q)$	$\lvert g^{eq}_{\mathcal{Q}_5}\rvert^2/M^2_{\mathcal{Q}_5}$	$\mathcal{O}_{qe}$
	$(\bar{\mathbf{3}}_u,\bar{\mathbf{3}}_q)$	$2\lvert g^{uq}_{\mathcal{Q}_5}\rvert^2/(3M^2_{\mathcal{Q}_5})$	$\mathcal{O}^{(1)}_{qu} - 3\mathcal{O}^{(8)}_{qu}$
$\mathcal{X} \sim (\mathbf{3},\mathbf{3})_{\frac{2}{3}}$	$(\bar{\mathbf{3}}_\ell,\mathbf{3}_q)$	$-\lvert g_{\mathcal{X}}\rvert^2/(8M^2_{\mathcal{X}})$	$3\mathcal{O}^{(1)}_{\ell q} - \mathcal{O}^{(3)}_{\ell q}$
$\mathcal{Y}_1 \sim (\bar{\mathbf{6}},\mathbf{2})_{\frac{1}{6}}$	$(\bar{\mathbf{3}}_d,\bar{\mathbf{3}}_q)$	$\lvert g_{\mathcal{Y}_1}\rvert^2/(3M^2_{\mathcal{Y}_1})$	$2\mathcal{O}^{(1)}_{qd} + 3\mathcal{O}^{(8)}_{qd}$
$\mathcal{Y}_5 \sim (\bar{\mathbf{6}},\mathbf{2})_{-\frac{5}{6}}$	$(\bar{\mathbf{3}}_u,\bar{\mathbf{3}}_q)$	$\lvert g_{\mathcal{Y}_5}\rvert^2/(3M^2_{\mathcal{Y}_5})$	$2\mathcal{O}^{(1)}_{qu} + 3\mathcal{O}^{(8)}_{qu}$
$\mathcal{G} \sim (\mathbf{8},\mathbf{1})_0$	$\mathbf{8}_q$	$-(g^q_{\mathcal{G}})^2/(144M^2_{\mathcal{G}})$	$11\mathcal{O}^{(1)D}_{qq} - 9\mathcal{O}^{(1)E}_{qq} + 9\mathcal{O}^{(3)D}_{qq} - 3\mathcal{O}^{(3)E}_{qq}$
	$\mathbf{8}_u$	$(g^u_{\mathcal{G}})^2/(36M^2_{\mathcal{G}})$	$3\mathcal{O}^E_{uu} - 5\mathcal{O}^D_{uu}$
	$\mathbf{8}_d$	$(g^d_{\mathcal{G}})^2/(36M^2_{\mathcal{G}})$	$3\mathcal{O}^E_{dd} - 5\mathcal{O}^D_{dd}$
$\mathcal{G}_1 \sim (\mathbf{8},\mathbf{1})_1$	$(\bar{\mathbf{3}}_d,\mathbf{3}_u)$	$\lvert g_{\mathcal{G}_1}\rvert^2/(9M^2_{\mathcal{G}_1})$	$-4\mathcal{O}^{(1)}_{ud} + 3\mathcal{O}^{(8)}_{ud}$
$\mathcal{H} \sim (\mathbf{8},\mathbf{3})_0$	$\mathbf{8}_q$	$-(g_{\mathcal{H}})^2/(576M^2_{\mathcal{H}})$	$27\mathcal{O}^{(1)D}_{qq} - 9\mathcal{O}^{(1)E}_{qq} - 7\mathcal{O}^{(3)D}_{qq} - 3\mathcal{O}^{(3)E}_{qq}$

Field	Irrep	Normalization	Operator
$N \sim (\mathbf{1},\mathbf{1})_0$	$\mathbf{3}_\ell$	$\lvert\lambda_N\rvert^2/(4M^2_N)$	$\mathcal{O}^{(1)}_{\phi\ell} - \mathcal{O}^{(3)}_{\phi\ell}$
$E \sim (\mathbf{1},\mathbf{1})_{-1}$	$\mathbf{3}_\ell$	$-\lvert\lambda_E\rvert^2/(4M^2_E)$	$\mathcal{O}^{(1)}_{\phi\ell} + \mathcal{O}^{(3)}_{\phi\ell} - [2y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Delta_1 \sim (\mathbf{1},\mathbf{2})_{-\frac{1}{2}}$	$\mathbf{3}_e$	$\lvert\lambda_{\Delta_1}\rvert^2/(2M^2_{\Delta_1})$	$\mathcal{O}_{\phi e} + [y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Delta_3 \sim (\mathbf{1},\mathbf{2})_{-\frac{3}{2}}$	$\mathbf{3}_e$	$-\lvert\lambda_{\Delta_3}\rvert^2/(2M^2_{\Delta_3})$	$\mathcal{O}_{\phi e} - [y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Sigma \sim (\mathbf{1},\mathbf{3})_0$	$\mathbf{3}_\ell$	$\lvert\lambda_\Sigma\rvert^2/(16M^2_\Sigma)$	$3\mathcal{O}^{(1)}_{\phi\ell} + \mathcal{O}^{(3)}_{\phi\ell} + [4y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$\Sigma_1 \sim (\mathbf{1},\mathbf{3})_{-1}$	$\mathbf{3}_\ell$	$\lvert\lambda_{\Sigma_1}\rvert^2/(16M^2_{\Sigma_1})$	$\mathcal{O}^{(3)}_{\phi\ell} - 3\mathcal{O}^{(1)}_{\phi\ell} + [2y^*_e\mathcal{O}_{e\phi} + \text{h.c.}]$
$U \sim (\mathbf{3},\mathbf{1})_{\frac{2}{3}}$	$\mathbf{3}_q$	$\lvert\lambda_U\rvert^2/(4M^2_U)$	$\mathcal{O}^{(1)}_{\phi q} - \mathcal{O}^{(3)}_{\phi q} + [2y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
$D \sim (\mathbf{3},\mathbf{1})_{-\frac{1}{3}}$	$\mathbf{3}_q$	$-\lvert\lambda_D\rvert^2/(4M^2_D)$	$\mathcal{O}^{(1)}_{\phi q} + \mathcal{O}^{(3)}_{\phi q} - [2y^*_d\mathcal{O}_{d\phi} + \text{h.c.}]$
$Q_1 \sim (\mathbf{3},\mathbf{2})_{\frac{1}{6}}$	$\mathbf{3}_u$	$-\lvert\lambda^u_{Q_1}\rvert^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi u} - [y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
	$\mathbf{3}_d$	$\lvert\lambda^d_{Q_1}\rvert^2/(2M^2_{Q_1})$	$\mathcal{O}_{\phi d} + [y^*_d\mathcal{O}_{d\phi} + \text{h.c.}]$
$Q_5 \sim (\mathbf{3},\mathbf{2})_{-\frac{5}{6}}$	$\mathbf{3}_d$	$-\lvert\lambda_{Q_5}\rvert^2/(2M^2_{Q_5})$	$\mathcal{O}_{\phi d} - [y^*_d\mathcal{O}_{d\phi} + \text{h.c.}]$
$Q_7 \sim (\mathbf{3},\mathbf{2})_{\frac{7}{6}}$	$\mathbf{3}_u$	$\lvert\lambda_{Q_7}\rvert^2/(2M^2_{Q_7})$	$\mathcal{O}_{\phi u} + [y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
$T_1 \sim (\mathbf{3},\mathbf{3})_{-\frac{1}{3}}$	$\mathbf{3}_q$	$\lvert\lambda_{T_1}\rvert^2/(16M^2_{T_1})$	$\mathcal{O}^{(3)}_{\phi q} - 3\mathcal{O}^{(1)}_{\phi q} + [2y^*_d\mathcal{O}_{d\phi} + 4y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$
$T_2 \sim (\mathbf{3},\mathbf{3})_{\frac{2}{3}}$	$\mathbf{3}_q$	$\lvert\lambda_{T_2}\rvert^2/(16M^2_{T_2})$	$\mathcal{O}^{(3)}_{\phi q} + 3\mathcal{O}^{(1)}_{\phi q} + [4y^*_d\mathcal{O}_{d\phi} + 2y^*_u\mathcal{O}_{u\phi} + \text{h.c.}]$

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

Greljo, AP [2305.08898]

Leading directions: Phenomenology

- 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
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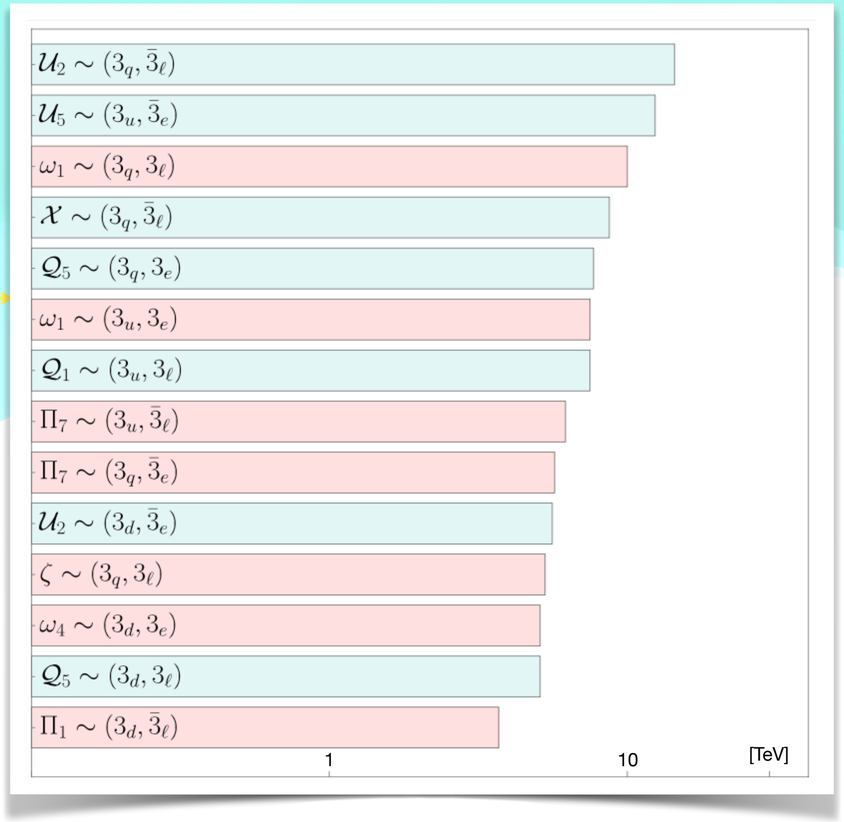

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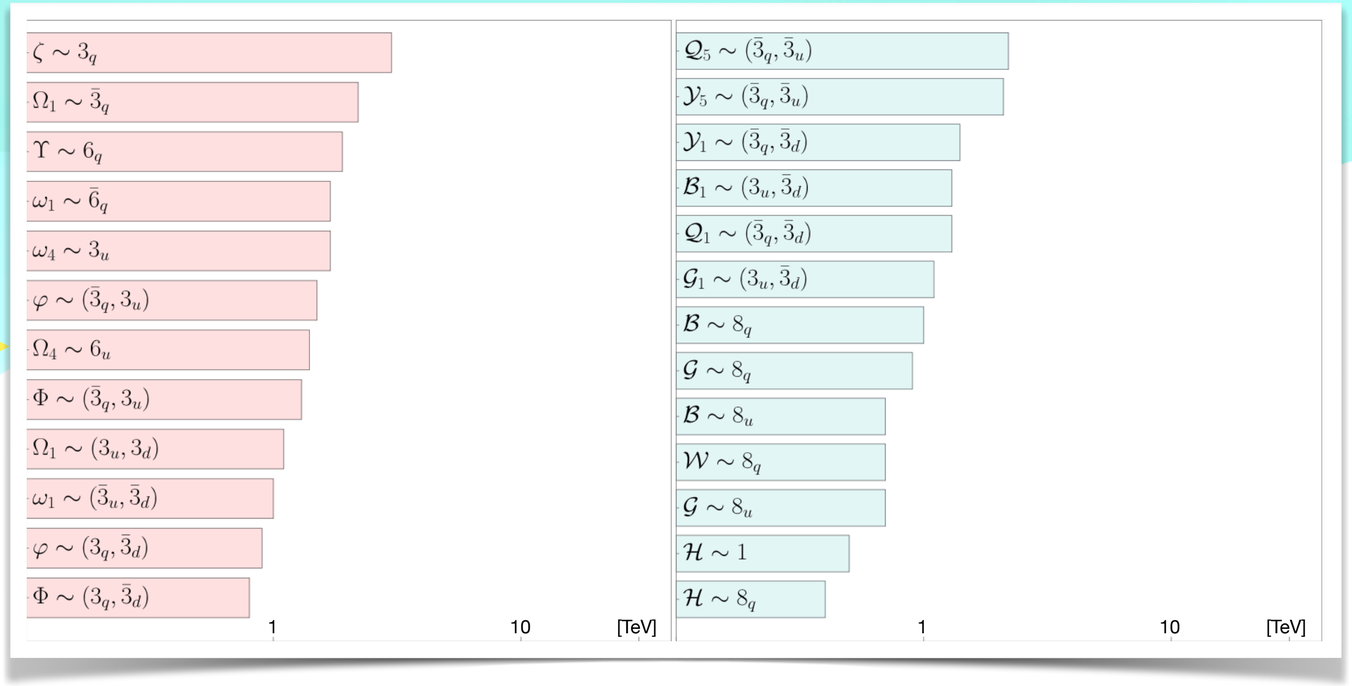

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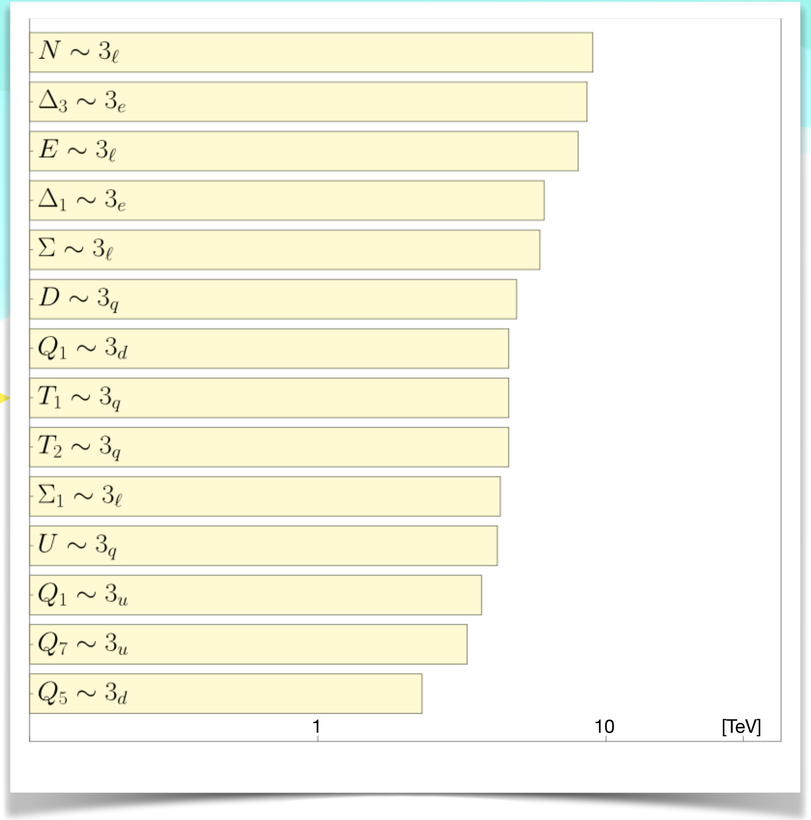

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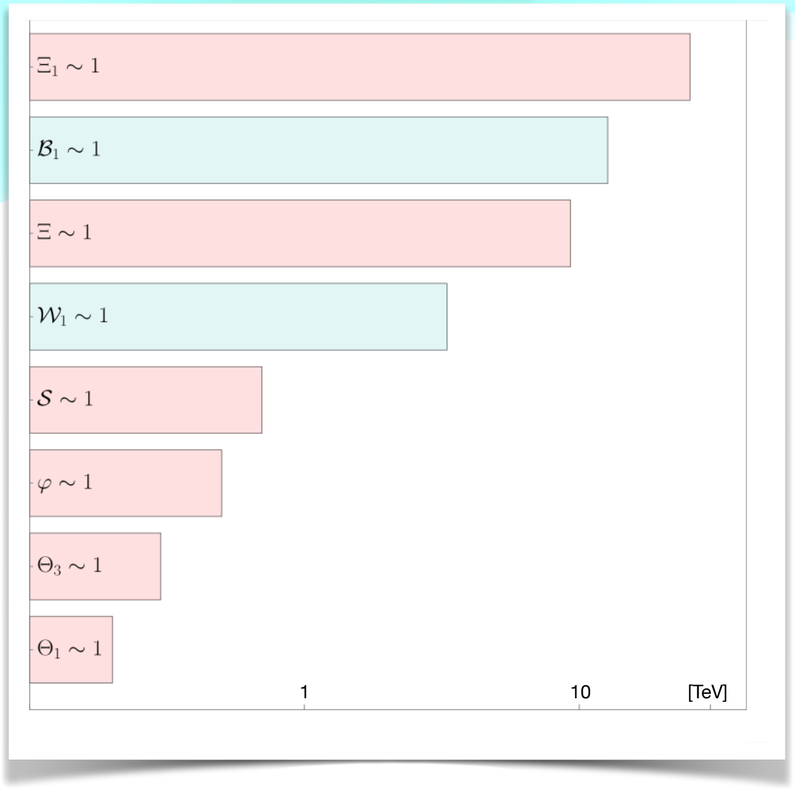

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- Comprehensive bottom-up study as the interplay of flavor symmetries and UV completions
- Several interesting improvements and promising directions for future study
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  - $U(2)^5$ directions

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Greljo, AP, Smolkovič [work in progress]

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