



# Effective Operator Bases For SMEFT and Chiral EFT

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[ Hao-Lin Li, Zhe Ren, Ming-Lei Xiao, **Yu**, Yu-Hui Zheng,  
2201.04639 ]

[ Li, Yu-Han Ni, Xiao, **Yu**, 2204.03660 ]

[ Sun, Xiao, **Yu**, 2206.07722, 2210.xxxxx ]

[ Sun, Yi-Ning Wang, **Yu**, 2211.xxxxx ]

[ Li, Ren, Shu, Xiao, **Yu**, Zheng, 2005.00008 ]

[ Li, Ren, Xiao, **Yu**, Zheng, 2007.07899 ]

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[ Li, Ren, Xiao, **Yu**, Zheng, 2105.09323 ]

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# Outline

- Introduction
- Standard Model EFT and its UV Completion

[ Li, Ren, Xiao, **Yu**, Zheng, 2201.04639 ]

[ Li, Yu-Han Ni, Xiao, **Yu**, 2204.03660 ]

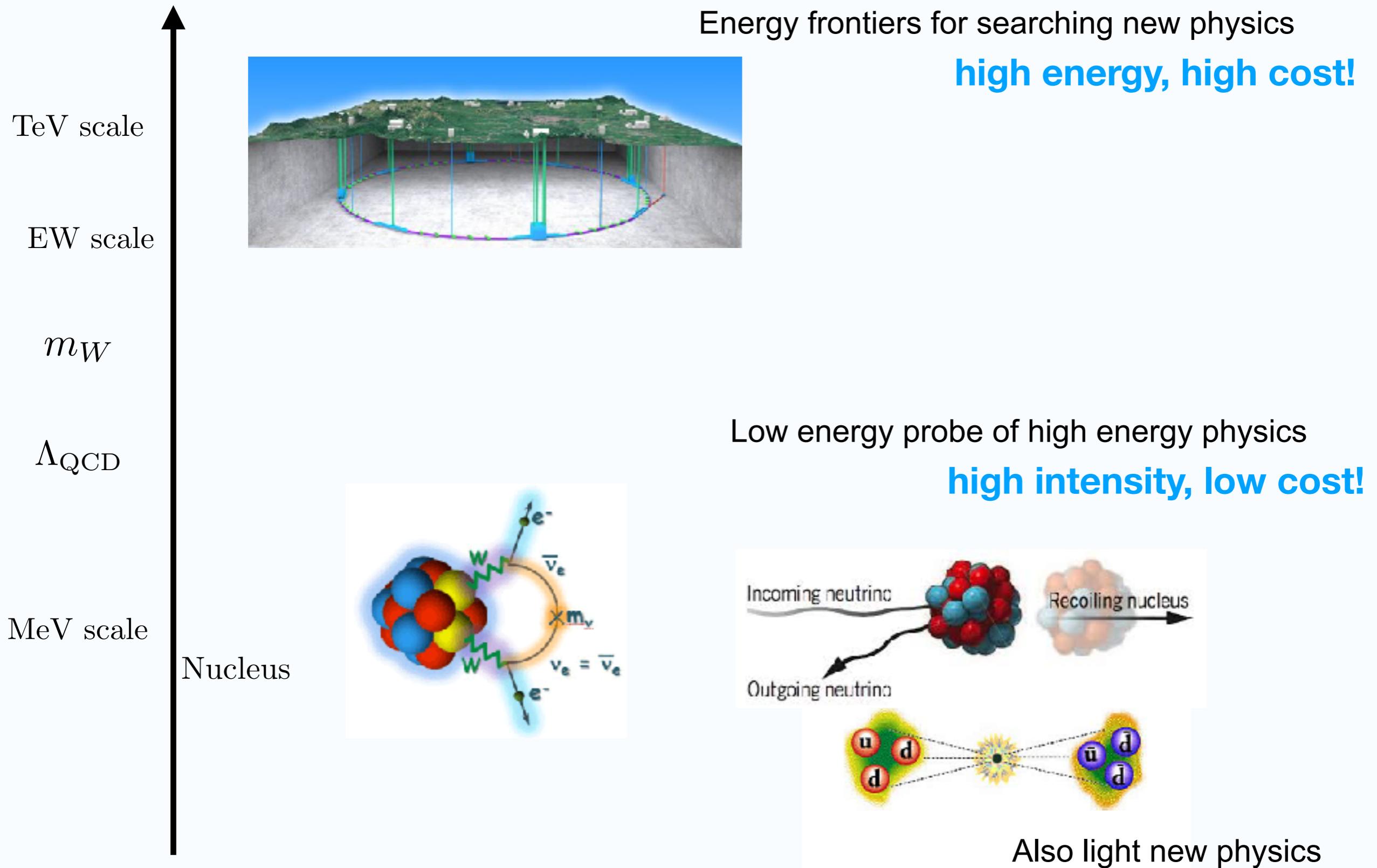
- Chiral EFT for EW and QCD

[ Sun, Xiao, **Yu**, 2206.07722, 2210.xxxxx ]

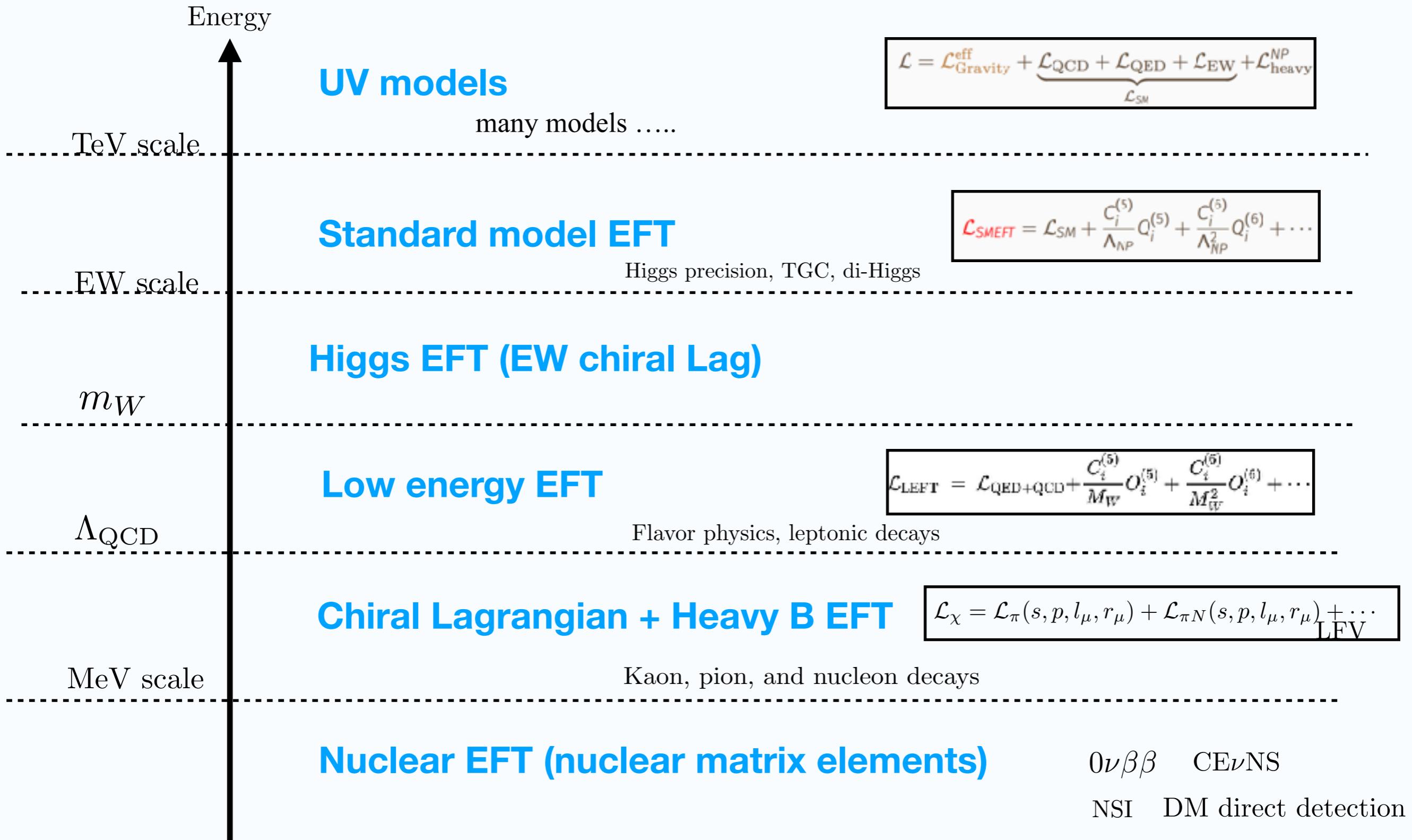
[ Sun, Wang, **Yu**, 2211.xxxxx ]

- Summary

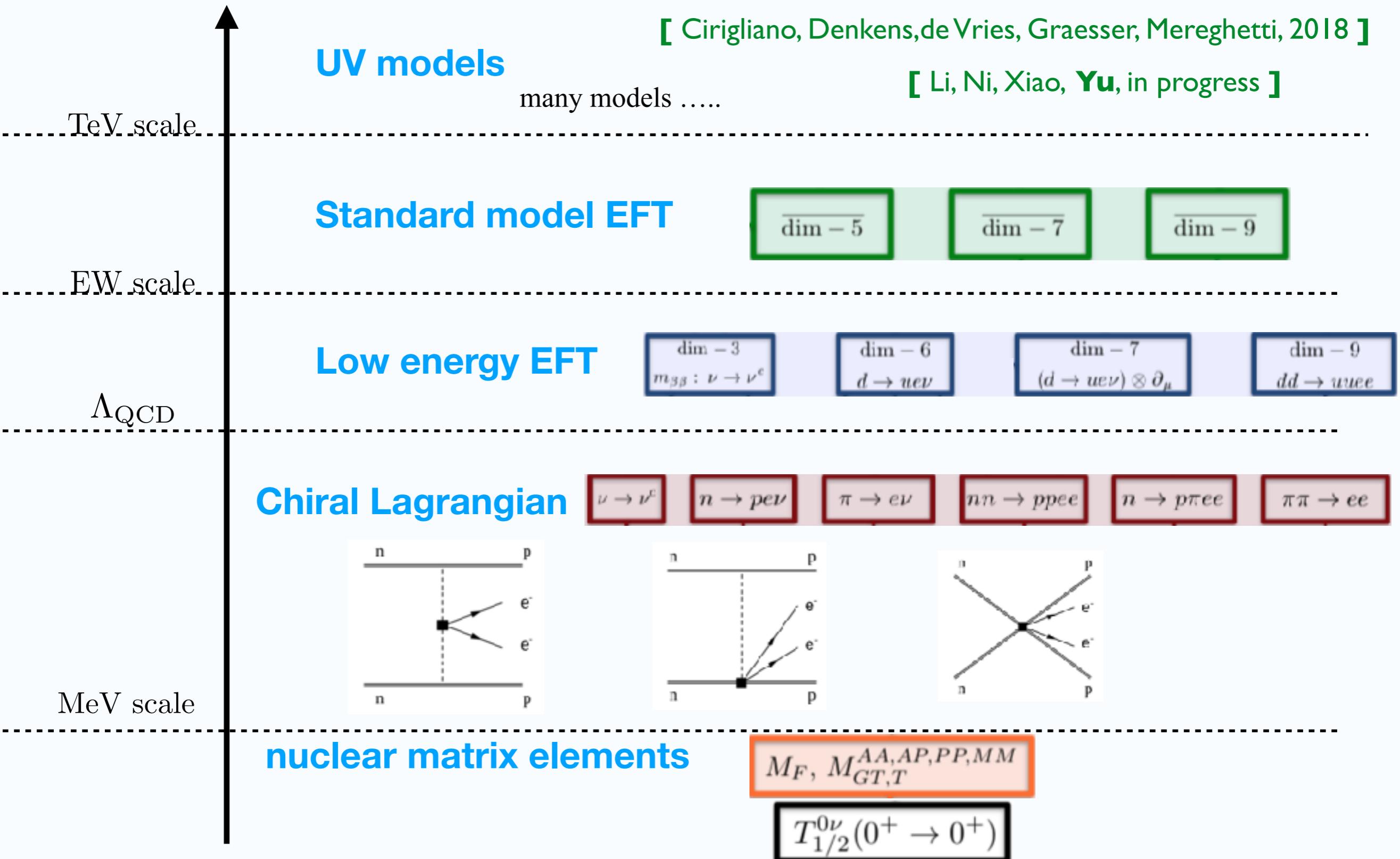
# Search For New Physics



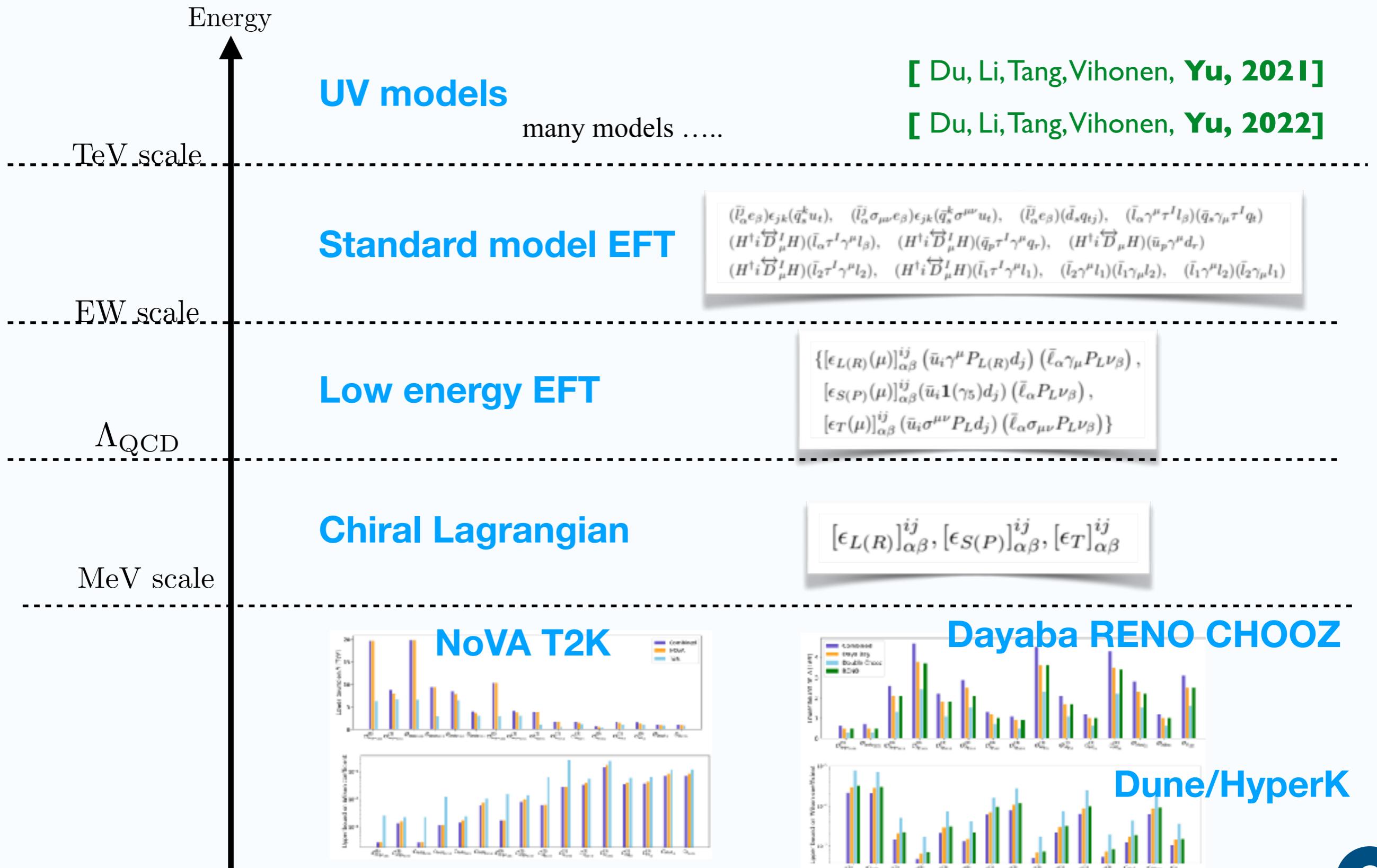
# EFT Ladder



# Neutrinoless Double Beta Decay



# 4-Fermi EFT: From Beta to NSI



# **SMEFT Operators and UV Resonances**

**Lectures on Effective Field Theories (video)**

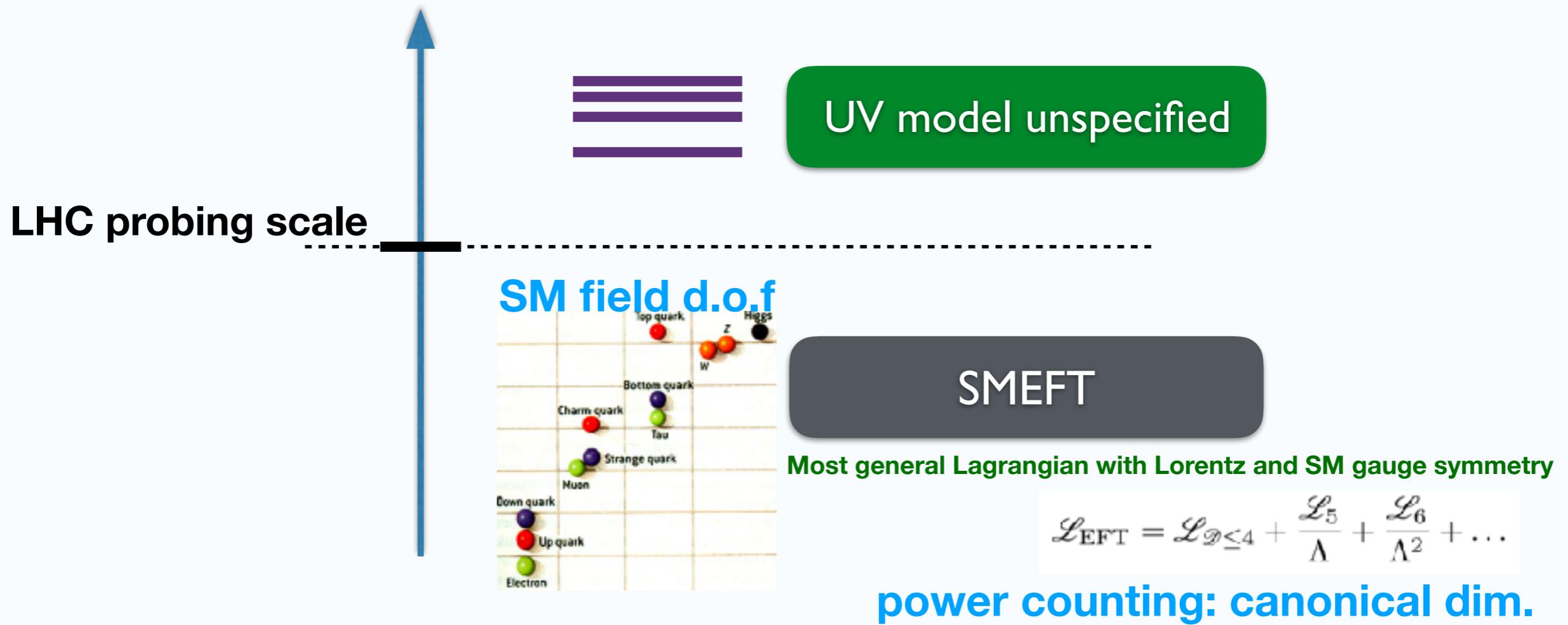
<https://indico.ihep.ac.cn/event/17771/page/1411-1o108>

**All things EFT seminar on SMEFT Operator Basis**

<https://www.koushare.com/video/videodetail/12645>

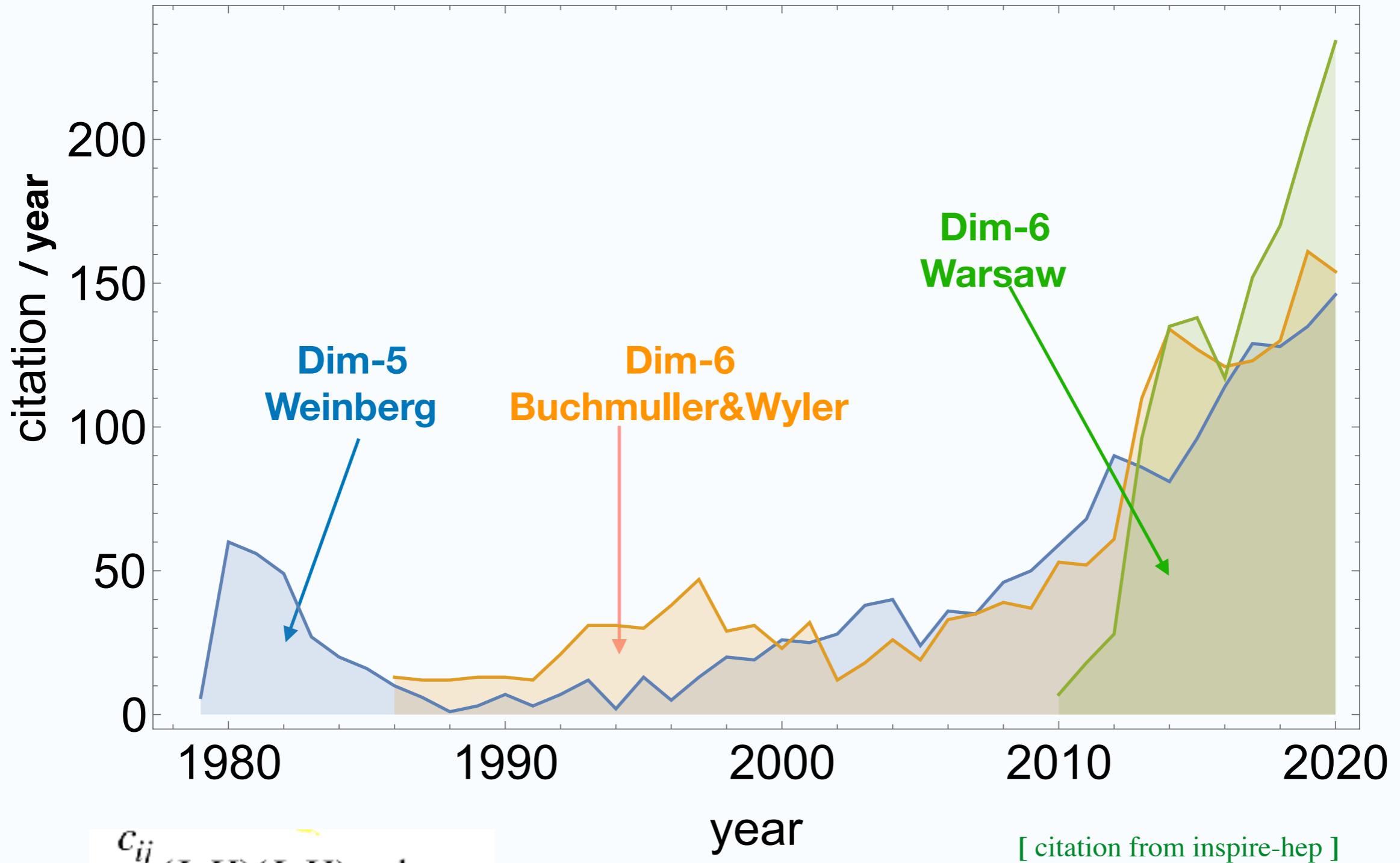
# SMEFT

Standard model effective field theory (SMEFT)



SMEFT provides systematic parametrization of  
... all possible Lorentz inv. new physics!

# SMEFT Operators



# Dim-6 Operators

# Why completing dim-6 took more than 25 years?

tedious and prone-to-error

$O_{\varphi} = (\varphi^\dagger \varphi)^3$ ,	$O_G = f_{ABC} G_A^{B\mu} G_C^{C\mu}$ ,
$O_{\varphi\varphi} = [\partial_\mu(\varphi^\dagger \varphi)] \partial^\mu(\varphi^\dagger \varphi)$ ,	$O_{\tilde{G}} = f_{ABC} \tilde{G}_A^{B\mu} G_C^{C\mu}$ ,
$O_{\eta\eta} = (\varphi^\dagger \varphi)(\bar{\ell}\ell \varphi)$ ,	$O_W = \varepsilon_{IJK} W_\mu^{I\nu} W_\nu^{J\lambda} W_\lambda^{K\mu}$ ,
$O_{\eta\varphi} = (\varphi^\dagger \varphi)(\bar{q}q \varphi)$ ,	$O_{\tilde{W}} = \varepsilon_{IJK} \tilde{W}_\mu^{I\nu} W_\nu^{J\lambda} W_\lambda^{K\mu}$ ,
$O_{\eta\varphi} = (\varphi^\dagger \varphi)(\bar{q}d \varphi)$ ,	
$O_{\varphi G} = [(\varphi^\dagger \varphi) G_A^B] G^{B\mu}$ ,	$O_{\varphi G} = (\varphi^\dagger \varphi) \tilde{G}_A^B G^{B\mu}$ ,
$O_{\varphi W} = [(\varphi^\dagger \varphi) W_\mu^I] W^{I\mu}$ ,	$O_{\varphi W} = (\varphi^\dagger \varphi) \tilde{W}_\mu^I W^{I\mu}$ ,
$O_{\varphi B} = [(\varphi^\dagger \varphi) B_\mu] B^{\mu I}$ ,	$O_{\varphi B} = (\varphi^\dagger \varphi) \tilde{B}_\mu B^{\mu I}$ ,
$O_{\eta\varphi} = (\varphi^\dagger \tau^\mu \varphi) W_\mu^I B^{I\mu}$ ,	$O_{\varphi d} = (\varphi^\dagger \tau^\mu \varphi) \tilde{W}_\mu^I B^{I\mu}$ ,
$O_{\varphi\varphi}^{(1)} = (\varphi^\dagger \varphi) (D_\mu \varphi^\dagger D^\mu \varphi)$ ,	$O_{\varphi\varphi}^{(1)} = (\varphi^\dagger D^\mu \varphi) (D_\mu \varphi^\dagger \varphi)$ .

80

[Buchmuller, Wyler, 1986]

$O_{IR} = (\bar{D}^\mu \gamma_\mu D_\nu) / W^{\mu\nu},$	$O_{IS} = \bar{B}^\mu \gamma_\mu D_\nu / B^{\mu\nu},$	
$O_{S3} = i\bar{e}\gamma_\mu D_\nu e B^{\mu\nu},$		
$O_{S4} = i\bar{D}^\mu \gamma_\mu D_\nu q G^{\mu\nu},$		
$O_{SW} = i\bar{q} \gamma^\mu \gamma_\mu D_\nu q W^{\mu\nu},$	$O_{qB} = i\bar{q} \gamma_\mu D_\nu q B^{\mu\nu},$	
$O_{qG} = i\bar{q} \gamma^\mu \gamma_\mu D_\nu q G^{\mu\nu},$		
$O_{L3} = i\bar{D}^\mu \gamma_\mu D_\nu u B^{\mu\nu},$		
$O_{L4} = i\bar{D}^\mu \gamma_\mu D_\nu u G^{\mu\nu},$		
$O_{L5} = i\bar{D}^\mu \gamma_\mu D_\nu d B^{\mu\nu},$		
$O_{L6} = i\bar{D}^\mu \gamma_\mu D_\nu d G^{\mu\nu},$		
$O_{L7} = (\bar{D}_\mu \bar{D}^\mu) D^\mu \phi,$	$O_{D_0} = (D_\mu \bar{D}^\mu) D^\mu \phi,$	
$O_{D_0} = (\bar{q} D_\mu q) D^\mu \bar{\psi},$	$O_{D_0} = (D_\mu \bar{q} q) D^\mu \bar{\psi},$	$O_{\bar{\psi} t}^{(1)} = i(\bar{\psi}^\dagger D_\mu \bar{p})(\bar{t} \gamma^\mu t),$
$O_{D_2} = (\bar{q} D_\mu q) D^\mu \phi,$	$O_{D_2} = (D_\mu \bar{q} q) D^\mu \bar{\psi},$	$O_{\bar{\psi} t}^{(2)} = i(\bar{\psi}^\dagger D_\mu \tau^a \bar{p})(\bar{t} \gamma^\mu \tau^a t),$
$O_{SW} = (\bar{D}^\mu \gamma^\nu \gamma^\lambda \epsilon) \bar{q} W_{\mu\nu}^\lambda,$	$O_{SW} = (\bar{D}^\mu \gamma^\nu \epsilon) \bar{q} p B_{\mu\nu},$	$O_{\bar{\psi} s} = i(\bar{\psi}^\dagger D_\mu \bar{p})(\bar{s} \gamma^\mu s),$
$O_{SU} = (\bar{q} \gamma^\mu \gamma^\lambda \epsilon) \bar{q} G_{\mu\nu}^\lambda,$	$O_{\bar{\psi} q}^{(1)} = i(\bar{\psi}^\dagger D_\mu \bar{p})(\bar{q} \gamma^\mu q),$	
$O_{SU} = (\bar{q} \gamma^\mu \gamma^\lambda u) \bar{q} W_{\mu\nu}^\lambda,$	$O_{SU} = (\bar{q} \gamma^\mu \epsilon) \bar{q} B_{\mu\nu},$	$O_{\bar{\psi} q}^{(2)} = i(\bar{\psi}^\dagger D_\mu \bar{p})(\bar{q} \gamma^\mu q),$
$O_{SU} = (\bar{q} \gamma^\mu \gamma^\lambda d) \bar{q} G_{\mu\nu}^\lambda,$	$O_{\bar{\psi} u} = i(\bar{\psi}^\dagger D_\mu \bar{p})(\bar{u} \gamma^\mu u),$	
$O_{SU} = (\bar{q} \gamma^\mu \gamma^\lambda \epsilon) \bar{q} \phi A_{\mu\nu}^\lambda,$	$O_{\bar{\psi} d} = i(\bar{\psi}^\dagger D_\mu \bar{p})(\bar{d} \gamma^\mu d),$	

$$O_{\text{out}} = \left( \frac{\partial O}{\partial x} - \tau \cdot d \right) \in W_{\text{out}}, \quad O_{\text{out}} = \left( \frac{\partial O}{\partial x} - \tau \cdot d \right) \otimes \rho_{\text{out}}, \quad O_{\text{out}} = \delta(x) \otimes I.$$

$$G_{\mu\nu}^{(1,1)} = \frac{1}{2} (\partial_\mu \phi_1) (\partial_\nu \phi_1^*) - G_{\mu\nu}^{(0,0)} = \frac{1}{2} (\partial_\mu \phi_2) (\partial_\nu \phi_2^*),$$

$$O_{qq}^{(1,2)} = \frac{1}{2} (\bar{q} \gamma_\mu \tau^i q) (\bar{q} \gamma^\mu \tau^i q), \quad O_{qq}^{(3,2)} = \frac{1}{2} (\bar{q} \gamma_\mu \lambda^{ik} \tau^i q) (\bar{q} \gamma^\mu \lambda^{ik} \tau^i q),$$

$$O_{\mu}^{\Sigma} = (\bar{c} \gamma_{\mu} c) (q \gamma^{\mu} q), \quad O_{\mu}^{\Xi} = (\bar{c} \gamma_{\mu} \tau^i c) (q \gamma^{\mu} \tau^i q).$$

$$O_{\alpha} = \frac{1}{2}(e\gamma_{\alpha}e)(e\gamma^{\alpha}e), \quad O_{\alpha\beta} = \frac{1}{2}(e\gamma_{\alpha}e)(e\gamma^{\beta}e),$$

$$G_{11}^{(1)} = \{(\theta_{T_1}, u), (\theta_{T_1}^{-1}, u)\}, \quad G_{12}^{(1)} = \{(\theta_{T_2}, A^{-1}u), (\theta_{T_2}^{-1}, A^{-1}u)\}, \quad O_{11} = (Id)$$

$$G_{11}^{(2)} = \{(dy, d)(J_T^{-1}, d)\}, \quad G_{12}^{(2)} = \{(J_T, A^{-1}d)(J_T^{-1}, A^{-1}d)\}, \quad O_{12} = (Id)$$

$$O_{\infty} = (\bar{e} y_2 e) (\bar{w} y^* w), \quad O^{(1)}_{\infty} = (\bar{e} y_2 e)$$

$$O_{\alpha\beta} = (\partial Y_\alpha d) \cdot (d Y^\beta d), \quad O_{\alpha\beta}^{(1)} = (\partial Y_\alpha d^*) \cdot (d Y^\beta d^*), \quad O_{\alpha\beta}^{(2)} = (\bar{q} d)$$

$$O_{\mu\nu} = (\tilde{J}\epsilon)$$

## Equation of motion (Field redefinition)

$$(D^\mu D_\mu \varphi)^j = m^2 \varphi^j - \lambda (\varphi^\dagger \varphi) \varphi^j - \bar{e} \Gamma_e^\dagger e^j + \varepsilon_{jk} \bar{q}^k \Gamma_u u - \bar{d} \Gamma_d^\dagger q^j$$

$$i\not{\!}Dl = \Gamma_e e \varphi, \quad i\not{\!}De = \Gamma_e^\dagger \varphi^\dagger l, \quad i\not{\!}Dq = \Gamma_u u \tilde{\varphi} + \Gamma_d d \varphi, \quad i\not{\!}Du = \Gamma_u^\dagger \tilde{\varphi}^\dagger q,$$

$$(D^\mu W_{\mu a})^I = \frac{g}{2} \left( \tilde{\varphi}^\dagger i \not{\!}D_\mu^I \varphi + \bar{l} \gamma_\mu \tau^I l + \bar{q} \gamma_\mu \tau^I q \right),$$

# Covariant derivative commutator

$$[D_\beta, D_\alpha] \sim X_{\beta\alpha}$$

**Bianchi identity**  $D_{[\rho} X_{\mu\nu]} = 0$

## Integration by part (total derivatives)

$$(D^n\varphi)^\dagger(D^m\varphi) = -(D^{n+1}\varphi)^\dagger(D^{m-1}\varphi) + \partial \left[ (D^n\varphi)^\dagger(D^{m-1}\varphi) \right]$$

## Fierz identity

$$T_{\alpha\beta}^A T_{\kappa\lambda}^A = \frac{1}{2}\delta_{\alpha\lambda}\delta_{\kappa\beta} - \frac{1}{6}\delta_{\alpha\beta}\delta_{\kappa\lambda}$$

$$\tau_{jk}^I \tau_{mn}^J = 2\delta_{jn}\delta_{mk} - \delta_{jk}\delta_{mn}$$

$X^3$		$\varphi^k$ and $\varphi^l D^3$		$\varphi^3 \varphi^k$	
$Q_U$	$f^{ABC} G_u^{A\mu} G_v^{B\mu} G_w^{C\mu}$	$Q_V$	$(\varphi^l \varphi)^k$	$Q_{\psi\varphi}$	$(\varphi^l \varphi) (\bar{\psi}_\mu \gamma^\nu)$
$Q_G$	$f^{ABC} \bar{G}_u^{A\mu} G_v^{B\mu} G_w^{C\mu}$	$Q_{\psi\bar{\varphi}}$	$(\varphi^l \varphi) \square (\bar{\varphi}^l \varphi)$	$Q_{\psi\psi}$	$(\varphi^l \varphi) (\bar{\psi}_\mu \gamma^\nu)$
$Q_W$	$e^{ijk} W_u^{i\mu} W_v^{j\mu} W_w^{k\mu}$	$Q_{\psi D}$	$(\varphi^l D^\mu \varphi)^k$ / $(\varphi^l D_{\mu\nu})$	$Q_{\psi\rho}$	$(\varphi^l \varphi) (\bar{\rho}_\mu \gamma^\nu)$
$Q_B$	$e^{ijk} \bar{W}_u^{i\mu} W_v^{j\mu} W_w^{k\mu}$	$X^3 \varphi^3$		$\varphi^3 X \varphi$	
$Q_{\varphi G}$	$\varphi^l \varphi G_u^{A\mu} G_v^{B\mu}$	$Q_{\psi H}$	$(\bar{\ell}_\mu \sigma^{\mu\nu} \ell_\nu) \tau^l \varphi W_{\alpha\beta}^T$	$Q_{\varphi\varphi}^{(1)}$	$(\varphi^l \varphi \overleftrightarrow{D}_\mu \varphi) (\bar{\ell}_\mu \gamma^\nu)$
$Q_{\varphi\partial}$	$\varphi^l \varphi G_u^{A\mu} G_v^{B\mu}$	$Q_{\psi\varphi}$	$(\bar{\ell}_\mu \sigma^{\mu\nu} \ell_\nu) \varphi B_{\alpha\beta}$	$Q_{\varphi\varphi}^{(2)}$	$(\varphi^l \overleftrightarrow{D}_\mu \varphi) (\bar{\ell}_\mu \gamma^\nu)$
$Q_{\varphi T}$	$\varphi^l \varphi W_u^A W_v^B$	$Q_{\psi\psi}$	$(\bar{\ell}_\mu \sigma^{\mu\nu} T^\nu \ell_\nu) \varphi G_{\alpha\beta}^A$	$Q_{\varphi\psi}$	$(\varphi^l \overleftrightarrow{D}_\mu \varphi) (\bar{\ell}_\mu \gamma^\nu)$
$Q_{\varphi\overline{B}}$	$\varphi^l \varphi \bar{W}_u^A W_v^B$	$Q_{\psi W}$	$(\bar{\ell}_\mu \sigma^{\mu\nu} \ell_\nu) \tau^l \varphi W_{\alpha\beta}^T$	$Q_{\varphi\varphi}^{(3)}$	$(\varphi^l \overleftrightarrow{D}_\mu \varphi) (\bar{\ell}_\mu \gamma^\nu)$
$Q_{\varphi B}$	$\varphi^l \varphi B_u A_v$	$Q_{\psi\alpha}$	$(\bar{\ell}_\mu \sigma^{\mu\nu} \ell_\nu) \tau^l \varphi$	$\varphi^3 \varphi^2 D$	
$Q_{\varphi\bar{B}}$	$\varphi^l \varphi \bar{B}_u B_v$	$Q_{\psi\beta}$	$(\bar{\ell}_\mu \sigma^{\mu\nu} T^\nu \ell_\nu)$	$\varphi^3 \overleftrightarrow{D}_\mu \varphi$	
$Q_{\varphi W\alpha}$	$\varphi^l \tau^l \varphi W_u^A B_v^B$	$Q_{\psi\gamma}$	$(\bar{\ell}_\mu \sigma^{\mu\nu} \ell_\nu) \tau^l \varphi$	$\varphi^3 \overleftrightarrow{D}_\mu \varphi$	
$Q_{\varphi W\beta}$	$\varphi^l \tau^l \varphi \bar{W}_u^A B_v^B$	$Q_{\psi\delta}$	$(\bar{\ell}_\mu \sigma^{\mu\nu} \ell_\nu) \varphi$	$\varphi^3 \overleftrightarrow{D}_\mu \varphi$	
$(LL)(\bar{L}\bar{L})$		$(RR)(\bar{R}\bar{R})$		$(\bar{L}\bar{L})(\bar{R}\bar{R})$	
$Q_U$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\psi}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\psi}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$
$Q_G^{(1)}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\bar{\varphi}}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\psi}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$
$Q_G^{(2)}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\varphi}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\psi}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$
$Q_B^{(1)}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi H}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\psi}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$
$Q_B^{(2)}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi W}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\psi}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$
$(LR)(\bar{R}L)$ and $(LR)(\bar{L}\bar{R})$		$B$ -violating			
$Q_{\psi\psi}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\psi}$	$\epsilon^{\mu\nu\lambda} \epsilon_{\alpha\beta} [(\partial_\mu)^2 C \partial_\nu^\beta] [(\partial_\lambda)^2 C \partial_\alpha^\beta]$	$[(\partial_\mu)^2 C \partial_\nu^\beta]$	
$Q_{\psi\varphi}^{(1)}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\varphi}$	$\epsilon^{\mu\nu\lambda} \epsilon_{\alpha\beta} [(\partial_\mu)^2 C \partial_\nu^\beta] [(\partial_\lambda)^2 C \partial_\alpha^\beta]$	$[(\partial_\mu)^2 C \partial_\nu^\beta]$	
$Q_{\psi\varphi}^{(2)}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\psi}$	$\epsilon^{\mu\nu\lambda} \epsilon_{\alpha\beta} [(\partial_\mu)^2 C \partial_\nu^\beta] [(\partial_\lambda)^2 C \partial_\alpha^\beta]$	$[(\partial_\mu)^2 C \partial_\nu^\beta]$	
$Q_{\psi\psi}^{(1)}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\psi}$	$\epsilon^{\mu\nu\lambda} \epsilon_{\alpha\beta} [(\partial_\mu)^2 C \partial_\nu^\beta] [(\partial_\lambda)^2 C \partial_\alpha^\beta]$	$[(\partial_\mu)^2 C \partial_\nu^\beta]$	
$Q_{\psi\psi}^{(2)}$	$(\bar{L}_\mu \gamma_\nu L_\nu) (\bar{L}_\lambda \gamma^\lambda L_\lambda)$	$Q_{\psi\psi}$	$\epsilon^{\mu\nu\lambda} \epsilon_{\alpha\beta} [(\partial_\mu)^2 C \partial_\nu^\beta] [(\partial_\lambda)^2 C \partial_\alpha^\beta]$	$[(\partial_\mu)^2 C \partial_\nu^\beta]$	
$(L\bar{L})(\bar{R}\bar{L})$		59			

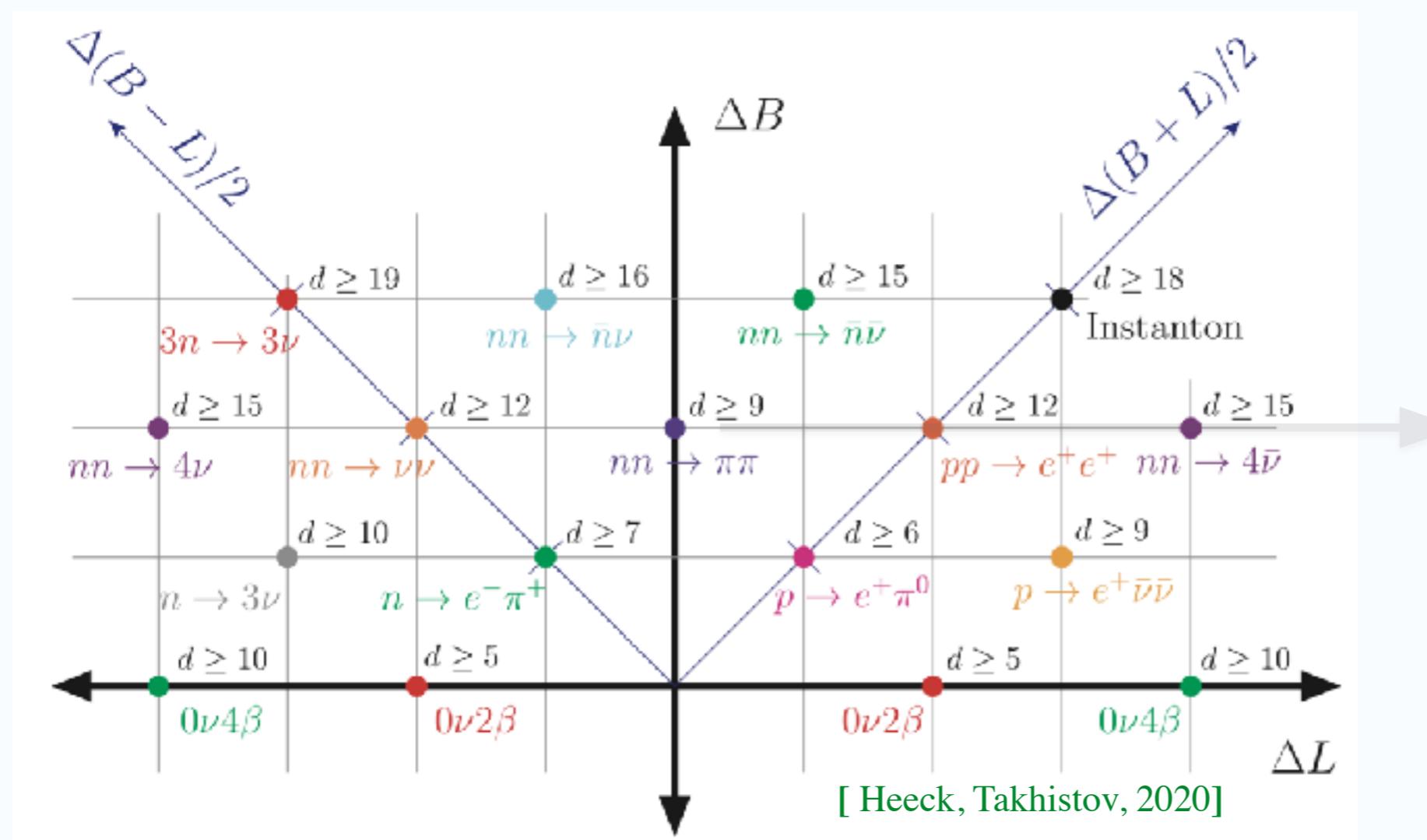
[Grzadkowski, Iskrzynski, Misiak, Rosiek, 2010]

$$80 - |-16 - 5 + 1| = 59$$

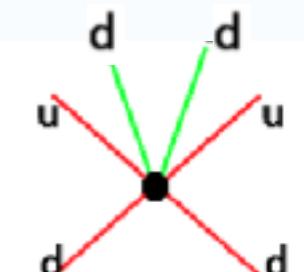
# Why High Dim Operator?

new physics without new particle: neutrino masses and baryon asymmetry

B and L violation



n-nbar oscillation



Dim-9

# Operator as Spinor Tensor

Modern view: operator as Young tensor and on-shell amplitude, with spin-statistics

Operator

$$W_{\mu\lambda} (e_{cp}\sigma^{\nu\lambda} D^\mu L_r) D_\nu H^\dagger.$$

Spinor Tensor

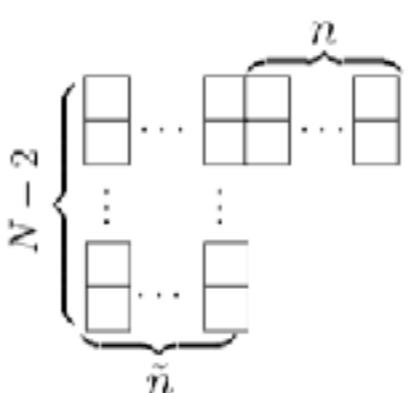


Symmetrize indices

$$\epsilon_{\alpha_1\alpha_3}\epsilon_{\alpha_1\alpha_3}\epsilon_{\alpha_2\alpha_4}\epsilon^{\hat{\alpha}_3\hat{\alpha}_4} F_1^{\alpha_1^2} \psi_2^{\alpha_2} (D\psi_3)^{\alpha_3^2}_{\hat{\alpha}_3} (D\phi_4)^{\alpha_4}_{\hat{\alpha}_4}$$

$$(D\psi)_{\alpha\beta\dot{\alpha}} = -\frac{1}{2}\epsilon_{\alpha\beta}(\not{D}\psi)_{\dot{\alpha}} + \frac{1}{2}(D\psi)_{(\alpha\beta)\dot{\alpha}}.$$

$SL(2,C) \times SU(N)$



$$\underbrace{(1, \dots, 1)}^{\#1}, \underbrace{(2, \dots, 2)}^{\#2}, \dots, \underbrace{(N, \dots, N)}^{\#N}$$

$\#i = \tilde{n} - 2h_i$

SSYT = Amplitude

1	1	1	2
2	3	3	4

$$\langle 13 \rangle \langle 13 \rangle \langle 24 \rangle [34]$$

1	1	1	3
2	2	3	4

$$\langle 12 \rangle \langle 13 \rangle \langle 34 \rangle [34]$$

On-shell

# Operator as Spinor Tensor

Dim-8 operators: 993 (44807) operators for 1 (3) generations

$\bar{\omega}$	0	2	4	6	8
0					
2					
4					
6					
8					

Unified construction of Lorentz & gauge structures by Young Tableau

$$\left( \begin{array}{|c|c|c|c|} \hline 1 & 1 & 1 & 2 \\ \hline 2 & 3 & 3 & 4 \\ \hline \end{array} \right) + \left( \begin{array}{|c|c|c|c|} \hline 1 & 1 & 1 & 3 \\ \hline 2 & 2 & 3 & 4 \\ \hline \end{array} \right) \times \begin{array}{|c|c|} \hline i & j \\ \hline k & l \\ \hline \end{array} = \boxed{(\tau^I)^i_j W_{\mu\nu}^I (e_{cp} D^\mu L_{ri}) D^\nu H^{\dagger j}} + \boxed{(\tau^I)^i_j W_{\mu\lambda}^I (e_{cp} \sigma^{\nu\lambda} L_{ri}) D^\mu D_\nu H^{\dagger j}}$$

# Operator as Spinor Tensor

## Young tensor method

$$BWHH^\dagger D^2$$

#1 = 3, #2 = 3, #3 = 1, #4 = 1

1	1	1	3
2	2	2	4

2

1	1	1	2
2	2	3	4

$$\tilde{\epsilon}_{\dot{\alpha}_3 \dot{\alpha}_4} \epsilon^{\alpha_1 \alpha_2} \epsilon^{\alpha_1 \alpha_2} \epsilon^{\alpha_3 \alpha_4}$$

$$B_L{}^{\alpha\beta} W_{L\alpha\beta} (DH^\dagger)^\gamma{}_\dot{\alpha} (DH)_{\gamma}{}^{\dot{\alpha}},$$

$$\langle 13 \rangle \langle 13 \rangle \langle 24 \rangle [34]$$

$$B_L{}^{\alpha\beta} W_{L\alpha}{}^\gamma (DH^\dagger)_{\beta\dot{\alpha}} (DH)_{\gamma}{}^{\dot{\alpha}}$$

$$\langle 12 \rangle \langle 13 \rangle \langle 34 \rangle [34]$$

No need to first list over-complete  
and remove redundancy

## Traditional method

$$BWHH^\dagger D^2$$

[ Hays, Martin, Sanz, Setford, 2018]

$$\begin{aligned}
 & (\mathcal{D}^2 H^\dagger) H B_{L,\mu\nu} W_L^{\mu\nu}, (\mathcal{D}^\mu \mathcal{D}_\nu H^\dagger) H B_{L,\mu\nu} W_L^{\mu\nu}, (\mathcal{D}_\mu \mathcal{D}^\nu H^\dagger) H B_{L,\mu\nu} W_L^{\mu\nu}, (B_\mu H^\dagger)(\mathcal{D}^\mu H) B_{L,\mu\nu} W_L^{\mu\nu}, \\
 & (\mathcal{D}_\mu H^\dagger)(\mathcal{D}^\mu H) B_{L,\mu\nu} W_L^{\mu\nu}, (\mathcal{D}^\nu H^\dagger)(\mathcal{D}_\mu H) B_{L,\mu\nu} W_L^{\mu\nu}, (\mathcal{D}_\mu H^\dagger) H (\mathcal{D}^\nu B_{L,\mu\nu}) W_L^{\mu\nu}, (\mathcal{D}_\nu H^\dagger) H (\mathcal{D}^\nu B_{L,\mu\nu}) W_L^{\mu\nu}, \\
 & (\mathcal{D}^\nu H^\dagger) H (B_\mu B_{L,\mu\nu}) W_L^{\mu\nu}, (B_\mu H^\dagger) H B_{L,\mu\nu} (\mathcal{D}^\nu W_L^{\mu\nu}), (B_\mu H^\dagger) H B_{L,\mu\nu} (\mathcal{D}^\nu W_L^{\mu\nu}), \\
 & H^\dagger (\mathcal{D}^2 H) B_{L,\mu\nu} W_L^{\mu\nu}, H^\dagger (\mathcal{D}^\mu \mathcal{D}_\nu H) B_{L,\mu\nu} W_L^{\mu\nu}, H^\dagger (\mathcal{D}^\mu \mathcal{D}_\nu H) B_{L,\mu\nu} (D_\mu W_L^{\mu\nu}), \\
 & H^\dagger (\mathcal{D}^\mu H) (D_\mu B_{L,\mu\nu}) W_L^{\mu\nu}, H^\dagger (D_\mu H) (\mathcal{D}^\nu B_{L,\mu\nu}) W_L^{\mu\nu}, H^\dagger (\mathcal{D}^\nu H) B_{L,\mu\nu} (D_\mu W_L^{\mu\nu}), \\
 & H^\dagger (D_\mu H) B_{L,\mu\nu} (\mathcal{D}^\nu W_L^{\mu\nu}), H^\dagger H (\mathcal{D}^\mu B_{L,\mu\nu}) W_L^{\mu\nu}, H^\dagger H (\mathcal{D}^\mu \mathcal{D}^\nu B_{L,\mu\nu}) W_L^{\mu\nu}, \\
 & H^\dagger H (D^\nu B_{L,\mu\nu}) (D_\mu W_L^{\mu\nu}), H^\dagger H (D^\nu B_{L,\mu\nu}) (D_\mu W_L^{\mu\nu}), H^\dagger H (D_\mu B_{L,\mu\nu}) (\mathcal{D}^\nu W_L^{\mu\nu}), H^\dagger H B_{L,\mu\nu} (\mathcal{D}^\nu W_L^{\mu\nu}), \\
 & H^\dagger H B_{L,\mu\nu} (D^\mu D_\nu W_L^{\mu\nu}), H^\dagger H B_{L,\mu\nu} (D_\mu \mathcal{D}^\nu W_L^{\mu\nu}). \tag{14}
 \end{aligned}$$

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EOM

$$\begin{aligned}
 & (DH^\dagger)_{\alpha\dot{\alpha}} (DH)_{\beta\dot{\beta}} B_{L\{\gamma\delta\}} W_{L\{\xi\eta\}} \epsilon^{\dot{\alpha}\beta} \epsilon^{\alpha\beta} \epsilon^\gamma \epsilon^{\xi\eta} \\
 & (DH^\dagger)_{\alpha\dot{\alpha}} (DH)_{\beta\dot{\beta}} B_{L\{\gamma\delta\}} W_{L\{\xi\eta\}} \frac{1}{2} \epsilon^{\alpha\beta} \epsilon^{\dot{\alpha}\dot{\beta}} (\epsilon^{\alpha\gamma} \epsilon^{\beta\eta} + \epsilon^{\beta\gamma} \epsilon^{\alpha\eta}) \\
 & (DH^\dagger)_{\alpha\dot{\alpha}} H (DE_L)_{\{\beta\gamma\delta\},\beta} W_{L\{\xi\eta\}} \epsilon^{\dot{\alpha}\dot{\beta}} \epsilon^{\alpha\beta} \epsilon^{\gamma\xi} \epsilon^{\delta\eta} \\
 & (DH^\dagger)_{\alpha\dot{\alpha}} H B_{L\{\xi\eta\}} (DW_L)_{\{\beta\gamma\delta\},\dot{\beta}} \epsilon^{\dot{\alpha}\dot{\beta}} \epsilon^{\alpha\beta} \epsilon^{\gamma\xi} \epsilon^{\delta\eta} \\
 & H^\dagger (DH)_{\alpha\dot{\alpha}} (DE_L)_{\{\beta\gamma\delta\},\beta} W_{L\{\xi\eta\}} \epsilon^{\dot{\alpha}\dot{\beta}} \epsilon^{\alpha\beta} \epsilon^{\gamma\xi} \epsilon^{\delta\eta} \\
 & H^\dagger (DH)_{\alpha\dot{\alpha}} B_{L\{\xi\eta\}} (DW_L)_{\{\beta\gamma\delta\},\dot{\beta}} \epsilon^{\alpha\dot{\beta}} \epsilon^{\alpha\beta} \epsilon^{\gamma\xi} \epsilon^{\delta\eta} \\
 & H^\dagger H (DB_L)_{\{\alpha\beta\gamma\},\dot{\alpha}} (DW_L)_{\{\xi\eta\dot{\beta}\},\dot{\beta}} \epsilon^{\dot{\alpha}\dot{\beta}} \epsilon^{\alpha\beta} \epsilon^{\gamma\xi} \epsilon^{\delta\eta}
 \end{aligned}$$

IBP

$$\begin{aligned}
 & B_L{}^{\alpha\beta} W_{L\alpha\beta} (DH^\dagger)^\gamma{}_\dot{\alpha} (DH)_{\gamma}{}^{\dot{\alpha}} \\
 & B_L{}^{\alpha\beta} W_{L\alpha}{}^\gamma (DH^\dagger)_{\beta\dot{\alpha}} (DH)_{\gamma}{}^{\dot{\alpha}}
 \end{aligned}$$

2

# SMEFT Operators

## Dimension-5

$$\epsilon_{ij}\epsilon_{mn}(L^iCL^m)H^jH^n$$

[Weinberg, 1979]

2

## Dimension-6

[Buchmuller, Wyler, 1986]

[Grzadkowski, Iskrzynski, Misiak, Rosiek, 2010]

[Lehman, 2014]

[ Henning, Lu, Melia, Murayama, 2015]

[Liao, Ma, 2016]

# Dimension-8

[ Li, Ren, Shu, Xiao, Yu, Zheng, 2020 ]

$T$	$(n, d)$	Subfamilies	$N_{\text{hyp}}$	$N_{\text{max}}$	$N_{\text{quasi}}$	Equation
4	(1, 9)	$E_6^3 + \lambda.c.$	13	26	26	(4.1)
	(3, 1)	$E_6^2 \phi^2 D + \lambda.c.$ $\phi^4 D^2 + \lambda.c.$ $E_6^2 \phi^2 \phi D^2 + \lambda.c.$ $E_6^2 \phi^2 D^3 + \lambda.c.$	22 4-1 66 8	22 38-11 32 12	22e <sub>1</sub> $12e_1^2 + 2e_2(2e_2 - 1)$ 22e <sub>1</sub> 12	(4.20) (4.75, 4.78, 4.80) (4.60) (4.10)
	(3, 2)	$E_6^2 \phi^2 e_1^2$ $E_6^2 \phi^2 \phi e_1^2 D$ $\phi^2 \eta^2 D^2$ $E_6^2 \phi^2 \phi D^2 + \lambda.c.$ $E_6^2 E_6 \phi^2 D^2$ $\phi \eta^2 \phi^2 D^2$ $\eta^2 D^2$	13 27 17-11 16 5 7 1	17 35 54-18 10 6 16 3	17 25e <sub>1</sub> $[(e_1)(2e_1^2 + 1) + 6e_1]$ 10e <sub>1</sub> 6 16e <sub>1</sub> 3	(4.11) (4.50, 4.51) (4.74, 4.79, 4.81) (4.60) (4.14) (4.11, 4.12) (4.8)
	(3, 6)	$E_6 \phi^2 + \lambda.c.$ $E_6^2 \phi^2 \phi + \lambda.c.$ $E_6^2 \phi^2 + \lambda.c.$	12-13 32 6	68-51 90 6	12e <sub>1</sub> $12e_1^2 + 2e_2(2e_2 - 1)$ 6	(4.86, 4.88, 4.89, 4.91) (4.47, 4.48) (4.11)
	(3, 11)	$E_6 \eta^2 \phi^2 + \lambda.c.$ $E_6^2 \eta^2 \phi + \lambda.c.$ $\eta^2 \phi^2 \phi + \lambda.c.$ $E_6 \eta^2 \phi^2 D + \lambda.c.$ $\eta^2 \phi^2 D^2 + \lambda.c.$ $E_6 \phi^2 \eta^2 + \lambda.c.$	84-79 32 32-13 38 6 4	174-93 30 140-78 32 36 6	$18e_1^2 [(2e_1^2 + 2) + 24e_1]$ 36e <sub>1</sub> $e_1^2 [(135e_1 - 1) + e_1^2(29e_1 + 3)]$ 52e <sub>1</sub> 36e <sub>1</sub> 6	(4.33, 4.39), (4.88, 4.97) (4.47, 4.48) (4.66, 4.69, 4.72) (4.30, 4.40) (4.28) (4.11)
6	(2, 6)	$\beta \phi^2 + \lambda.c.$ $E_6 \beta \phi^2 + \lambda.c.$ $E_6^2 \beta \phi^2 + \lambda.c.$	12±1 16 8	46-18 22 10	$5(5e_1 + e_1^2) + 2(20e_1^2 + \beta^2)$ 22e <sub>1</sub> 10	(4.57, 4.59, 4.62, 4.58) (4.38) (4.12)
	(1, 1)	$\phi^2 \eta^2 \phi^2$ $\eta^2 \phi^2 D^2$ $\eta^2 D^2$	22-13 7 1	22-11 18 2	$e_1^2 [(4e_1^2 + e_1 + 2)(2e_1^2 + 2e_1 - 1)]$ 18e <sub>1</sub> 2	(4.51, 4.55, 4.58, 4.63) (4.38, 4.45) (4.6)
	(1, 9)	$\eta^2 \phi^2 + \lambda.c.$	6	6	9e <sub>1</sub> <sup>2</sup>	(4.20)
8	(0, 0)	$\phi^2$	1	1	1	(4.8)
Total		$48$	$1714(47)$	$10034(348)$	$98(20e_1 - 31) + 128e_1^2(2e_1 - 3)$	

[Murphy, 2020]

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# Dimension-7

$1 : \psi^3 X H^2 + \text{h.c.}$	$2 : \psi^2 H^4 + \text{h.c.}$
$Q_{\bar{\nu} \nu X H^2}$	$\epsilon_{mn}(\tau^I)_{jk}(\bar{l}_p^m C \sigma^{\mu\nu} l_j^I) H^n H^k W_{\mu\nu}^I$
$Q_{\bar{\nu} \nu B H^2}$	$\epsilon_{mn} \epsilon_{ijk} (\bar{l}_p^m C \sigma^{\mu\nu} l_j^I) H^n H^k B_{\mu\nu}$
$3(B) : \psi^4 H + \text{h.c.}$	$3(B) : \psi^4 H + \text{h.c.}$
$Q_{\bar{\nu} \nu H}$	$\epsilon_{jkl} \epsilon_{mn} (\bar{e}_p l_j^I) (l_k^m C l_n^I) H^k$
$Q_{\bar{\nu} \nu d \bar{d} H}$	$\epsilon_{jkl} (\bar{d}_p l_j^I) (u_n C e_l) H^k$
$Q_{\bar{\nu} \nu q \bar{q} H}^{(1)}$	$\epsilon_{jkl} \epsilon_{mn} (\bar{d}_p l_j^I) (q_k^m C l_n^I) H^n$
$Q_{\bar{\nu} \nu q \bar{q} H}^{(2)}$	$\epsilon_{jlm} \epsilon_{kin} (\bar{d}_p l_j^I) (q_k^l C l_m^I) H^n$
$Q_{\bar{\nu} \nu q \bar{q} H}$	$\epsilon_{jkl} (\bar{e}_p u_n) (l_m C l_l^I) H^k$
$4 : \psi^2 H^2 D + \text{h.c.}$	$5(B) : \psi^4 D + \text{h.c.}$
$Q_{\bar{\nu} \nu H^2 D}$	$\epsilon_{mn} \epsilon_{ijk} (\bar{l}_p^m C \gamma^\mu e_\nu) H^n H^j D_\mu H^k$
$6 : \psi^2 H^2 D^2 + \text{h.c.}$	$5(B) : \psi^4 D + \text{h.c.}$
$Q_{\bar{\nu} \nu M^2 D D}^{(1)}$	$\epsilon_{jkl} \epsilon_{mn} (\bar{l}_p^l C D^\mu l_j^k) H^m (D_\mu H^n)$
$Q_{\bar{\nu} \nu M^2 D D}^{(2)}$	$\epsilon_{jlm} \epsilon_{kin} (\bar{l}_p^l C D^\mu l_j^k) H^m (D_\mu H^n)$
$Q_{\bar{\nu} \nu D^2 D}$	$\epsilon_{jkl} (\bar{l}_p \gamma^\mu q_k^m) (d_n^l C (D_\mu d_l^k))$
$Q_{\bar{\nu} \nu D^2 D}$	$\epsilon_{jkl} (\bar{e}_p \gamma^\mu q_k^m) (d_n^l C (D_\mu d_l^k))$

[Lehman, 2014]

[ Henning, Lu, Melia, Murayama, 2015]

[Liao, Ma, 2016]

## Dimension-9

[ Li, Ren, Xiao, Yu, Zheng, 2020 ]

$N$	$(n, \tilde{n})$	Class	$N_{\text{type}}$	$N_{\text{num}}$	$N_{\text{quanta}}$	Equation
4	(3, 2)	$\psi^2 \psi^2 D^3 + h.c.$	$\# + \tilde{\ell} + 2 = 0$	10	$\frac{1}{2} n_f^2 (7n_f^2 - 1)$	(5.50)(5.51)
		$\psi^1 \psi^2 D^4 + h.c.$	$\# + \tilde{\ell} + 2 = 0$	6	$3n_f(n_f + 1)$	(5.21)
5	(3, 1)	$F_L \psi^2 \psi^2 D + h.c.$	$\# + 12 + 6 + 0$	22	$32n_f^3$	(5.50)(5.53)
		$\psi^3 \psi^2 D^2 + h.c.$	$\# + \tilde{\ell} + 4 = 0$	100	$2m_f^4$	(4.45-5.48)
	$(2, 2)$	$F_L \psi^2 \psi^2 D^2 + h.c.$	$\# + \tilde{\ell} + 4 = 0$	24	$17n_f^2 - n_f$	(5.28)(5.29)
		$F_{\tilde{L}} \psi^2 \psi^2 D^2 + h.c.$	$\# + 12 + 6 + 0$	54	$4n_f^3 (5n_f + 1)$	(5.20)(5.50)
	$(2, 1)$	$\psi^2 \psi^2 D^2 + h.c.$	$\# + \tilde{\ell} + 4 = 0$	64	$n_f^3 (3n_f + 1)$	(4.45-5.48)
		$F_R \psi^2 \psi^2 D^2 + h.c.$	$\# + 12 + 6 + 0$	20	$2n_f (5n_f - 1)$	(5.28)(5.29)
	$(1, 0)$	$\psi^1 \psi^2 D^3$	$\# + \tilde{\ell} + 2 = 0$	6	$8n_f^2$	(5.15)
		$\psi^6 + h.c.$	$\# + \tilde{\ell} + 5 = 0$	116	$\frac{1}{2} n_f^2 (31n_f^2 + 53n_f^2 - 59n_f^2 + 129n_f + 6)$	(4.54-5.70)
6	$(3, 0)$	$F_L \psi^2 \psi^2 + h.c.$	$\# + 12 + 12 + 0$	102	$2n_f^2 (21n_f + 1)$	(4.54-5.46)
		$F_{\tilde{L}}^2 \psi^2 \psi^2 + h.c.$	$\# + \tilde{\ell} + 8 = 0$	26	$2n_f (3n_f + 2)$	(5.31)
	$(2, 1)$	$\psi^2 \psi^2 D + h.c.$	$\# + 26 + 29 + 4$	244	$\{n_f^2 (182n_f^2 - 9n_f^2 + 2n_f + 21)\}$	(4.53-5.69)
		$F_{\tilde{L}} \psi^2 \psi^2 D + h.c.$	$\# + 21 + 24 + 0$	12	$52n_f^3$	(5.54-5.56)
	$(1, 1)$	$F_L^2 \psi^2 \psi^2 + h.c.$	$\# + 0 + 8 = 0$	12	$2n_f (3n_f + 2)$	(5.30)
		$\psi^2 \psi^2 D^2 + h.c.$	$\# + 12 + 18 + 0$	186	$\frac{1}{2} n_f^2 (148n_f^2 + 1)$	(4.36-5.47)
	$(1, 0)$	$F_L \psi^2 \psi^2 D + h.c.$	$\# + \tilde{\ell} + 3 = 0$	15	$19n_f^2$	(5.28)
		$\psi^2 \psi^2 D^2 + h.c.$	$\# + 0 + 4 = 0$	24	$2n_f (3n_f + 1)$	(5.15)
7	$(2, 0)$	$\psi^1 \psi^2 + h.c.$	$\# + 6 + 5 = 0$	22	$\{n_f^2 (10n_f^2 - 1)\}$	(4.35-5.57)
		$F_L \psi^2 \psi^2 + h.c.$	$\# + \tilde{\ell} + 4 = 0$	8	$2n_f (2n_f - 1)$	(5.28)
	$(1, 1)$	$\psi^2 \psi^2 \phi^3$	$\# + 6 - 10 + 0$	24	$14n_f^3$	(5.35-5.27)
		$\psi \psi^2 \psi^2 D$	$\# + \tilde{\ell} + 2 = 0$	?	$2m_f^2$	(5.15)
8	$(1, 0)$	$\psi^2 \psi^2 + h.c.$	$\# + 0 + 2 = 0$	?	$n_f^2 + c_f$	(5.91)
		Total	42	6(132)164(4)	1262	$8 + 294 + 385 - 8(n_f - 1)$ $2862 + 47774 - 44874 + 386(n_f - 3)$

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# LEFT Operators

**SU(3) x U(1) symmetry massive fermion involved**

## Dimension-5

Dim-5 operators		
$N$ ( $n, \bar{n}$ )	Classes	$N_{\text{type}}$
3 (2,0)	$F_L^2 \psi_L^2 + h.c.$	10 + 9 + 2 + 0

10

[Jenkins, Manohar, Stoffer, 2017]

## Dimension-6

Dim-6 operators				
$N$ ( $n, \bar{n}$ )	Classes	$N_{\text{type}}$	$N_{\text{term}}$	
3 (3,0)	$F_L^3 + h.c.$	2 + 0 + 0 + 0	2	
4 (2,0)	$\psi_L^4 + h.c.$	14 + 12 + 8 + 2	78	
(1,1)	$\psi_L^2 \psi_R^2$	40 + 20 + 12 + 0	84	
Total		5	56 + 32 + 20 + 2	164

## Dimension-7

Dim-7 operators				
$N$ ( $n, \bar{n}$ )	Classes	$N_{\text{type}}$	$N_{\text{term}}$	
4 (3,0)	$F_L^2 \psi_L^2 + h.c.$	16 + 0 + 4 + 0	32	
(2,1)	$F_L^2 \psi_R^2 + h.c.$	16 + 0 + 4 + 0	24	
	$\psi_L^3 \psi_R D + h.c.$	50 + 32 + 22 +		
Total		6	82 + 32 + 30 +	166

120

[Liao, Ma, Wang, 2020]

[Li, Ren, Xiao, Yu, Zheng, 2020]

## Dimension-8

[Li, Ren, Xiao, Yu, Zheng, 2020]

$N$ ( $n, \bar{n}$ )	Subclasses	$N_{\text{type}}$	$N_{\text{term}}$	$N_{\text{operator}}$	Equation	
4 (1,0)	$F_L^4 + h.c.$	14	25	26	(4.16)	
(3,1)	$F_L^2 \psi_L^2 D + h.c.$ $\psi_L^4 D^2 + h.c.$ $\psi_L^2 \psi_R^2 D^2 + h.c.$ $F_L \psi_L^2 \psi_R^2 D + h.c.$	22 18 + 12 16 8	22 128 + 12 32 12	228 + 12 (4.21), (4.22), (4.23) (4.44) (4.11)		
(2,2)	$F_L^2 F_R^2$ $F_L F_R \psi_L^2 D$ $\psi_L^2 \psi_R^2 D^2$ $F_R \psi_L^2 \psi_R^2 D + h.c.$ $F_L F_R \psi_L^2 D^2$ $\psi_L^2 \psi_R^2 D^2$ $\psi_L^4 D^4$	14 27 17 + 8 16 5 7 1	17 35 [8] (2m_f^2 + 10) + m_f^2 160 4 160 4	(4.15) (4.26), (4.27) (4.44) (4.11) (4.31), (4.32) (4.8)		
5 (1,0)	$\psi_L^6 + h.c.$ $F_L^2 \psi_L^4 + h.c.$ $F_R^2 \psi_R^4 + h.c.$	12 + 18 32 4	100 + 50 90 4	128 + 50 + 10 (4.27), (4.28)		
(2,1)	$F_L \psi_L^2 \psi_R^2 D + h.c.$ $\psi_L^2 \psi_R^2 \phi + h.c.$ $\psi_L^2 \psi_R^2 D + h.c.$ $F_L \psi_L^2 \psi_R^2 D + h.c.$ $\psi_L^2 \psi_R^2 D^2 + h.c.$ $F_L \psi_L^2 D^2 + h.c.$	8 + 24 32 32 + 14 100 + 50 38 4	172 + 32 32 135 + 14 135 + 50 30 4	2m_f^2 (2m_f^2 - 2) + 2m_f^2 m_f^2 m_f^2 (135m_f^2 - 1) + m_f^2 (29m_f^2 + 3) 30m_f^2 30m_f^2 4	(4.58), (4.63), (4.88), (4.93), (4.94) (4.24), (4.25) (4.66), (4.69), (4.72) (4.26), (4.44) (4.27)	
6 (1,0)	$\psi_L^6 \psi_R^2 + h.c.$ $F_L \psi_L^2 \psi_R^2 + h.c.$ $F_R^2 \psi_R^4 + h.c.$	12 + 18 16 8	108 + 18 22 10	128 + 18 + 8 22m_f^2 10	(4.32), (4.39), (4.43), (4.44)	
(1,1)	$\psi_L^2 \psi_R^2 \psi_L^2$ $m_F^2 \psi_L^2 D$ $\psi_L^2 D^2$	20 + 14 7 1	20 + 14 11m_f^2 7	m_f^2 (2m_f^2 + m_f + 2) + 2m_f^2 (3m_f^2 - 1) 11m_f^2 7	(4.5), (4.55), (4.56), (4.63) (4.24), (4.25) (4.8)	
7 (1,0)	$\psi_L^2 \psi_R^2 + h.c.$	4	6	6m_f^2	(4.13)	
8 (1,0)	$\psi_L^8$	1	1	1	(4.3)	
Total		48	421 + 20 + 1376 + 100 + 600 (n_f = 1) + 4800 (n_f = 2)			

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[Murphy, 2020]

## Dimension-9

[Li, Ren, Xiao, Yu, Zheng, 2020]

$N$ ( $n, \bar{n}$ )	Classes	$N_{\text{type}}$	$N_{\text{term}}$	$N_{\text{operator}}$	Equation	
4 (3,2)	$\psi^4 \psi^2 D^4 + h.c.$ $\psi^4 \psi^2 D^2 + h.c.$	0 + 4 + 2 + 0	10	32m_f^4	(5.50), (5.51)	
5 (2,1)	$F_L \psi^2 \psi^2 D^4 + h.c.$ $\psi^2 \psi^2 D^2 + h.c.$ $F_R \psi^2 \psi^2 D^2 + h.c.$	0 + 12 + 6 + 0	72	32m_f^4	(5.50), (5.51)	
(2,2)	$F_L \psi^2 \psi^2 D^2 + h.c.$ $\psi^2 \psi^2 D^2 + h.c.$ $F_R \psi^2 \psi^2 D^2 + h.c.$ $\psi^2 \psi^2 \psi^2 D^2 + h.c.$	0 + 12 + 6 + 0 0 + 4 + 4 + 0	72 24	48m_f^4 17m_f^2 - m_f	(4.45), (4.48) (4.28), (4.29)	
6 (1,0)	$\psi^6 + h.c.$ $F_L \psi^4 + h.c.$ $F_R^2 \psi^2 + h.c.$	2 + 4 + 5 + 0	116	32m_f^6 (115m_f^4 + 32m_f^2 - 58m_f^2 + 129m_f + 6)	(5.54), (5.55)	
(2,1)	$\psi^2 \psi^2 \psi^2 + h.c.$ $\psi^2 \psi^2 \psi^2 D + h.c.$ $\psi^2 \psi^2 \psi^2 D^2 + h.c.$ $F_L \psi^2 \psi^2 \psi^2 D + h.c.$ $\psi^2 \psi^2 \psi^2 D^2 + h.c.$	4 + 26 + 29 + 4 0 + 12 + 13 + 0 0 + 0 + 8 + 0	248 102 20	2m_f^2 (3m_f^2 - 9m_f + 2m_f + 21) 2m_f^2 (2m_f + 1) 2m_f^2 (3m_f + 2)	(5.53), (5.59) (5.54), (5.56) (5.31)	
(2,1)	$\psi^2 \psi^2 \psi^2 \psi^2 + h.c.$ $\psi^2 \psi^2 \psi^2 \psi^2 D + h.c.$ $\psi^2 \psi^2 \psi^2 \psi^2 D^2 + h.c.$ $\psi^2 \psi^2 \psi^2 \psi^2 D^3 + h.c.$ $F_L \psi^2 \psi^2 \psi^2 \psi^2 D + h.c.$ $\psi^2 \psi^2 \psi^2 \psi^2 D^3 + h.c.$	4 + 26 + 29 + 4 0 + 0 + 8 + 0 0 + 12 + 18 + 0 0 + 0 + 8 + 0 15 24	248 86 86 15 24	2m_f^2 (3m_f^2 + 2) 2m_f^2 (3m_f^2 + 1) 2m_f^2 (3m_f^2 + 1) 12m_f^2 2m_f^2 (3m_f + 1)	(5.36), (5.42) (5.37) (5.41)	
7 (2,0)	$\psi^6 \psi^2 + h.c.$ $F_L \psi^4 \psi^2 + h.c.$ $F_R^2 \psi^2 \psi^2 + h.c.$	0 + 0 + 3 + 0	22	8m_f^2 (10m_f^2 - 1)	(5.35), (5.37)	
(1,1)	$\psi^2 \psi^2 \psi^2 \psi^2$ $\psi^2 \psi^2 \psi^2 \psi^2 D$	0 + 6 + 10 + 0 0 + 0 + 2 + 0	84 2	2m_f^2 (2m_f - 1)	(5.35), (5.37)	
8 (1,0)	$\psi^2 \psi^2 \psi^2 + h.c.$	0 + 0 + 2 + 0	2	m_f^2 + c_f	(5.39)	
Total		42	6 + 122 + 164 + 14	1262	8 + 234 + 345 + 0 (n_f = 1) 2942 + 42254 + 4 (874 + 486 (n_f = 2))	

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# vSMEFT and vLEFT

massive Majorana fermion involved

Dimension-5

Dim-5 operators			
$N$ ( $n, \bar{n}$ )	Classes	$N_{\text{sp}}$	$N_{\text{sm}}$
3 (2, 0)	$F_L \psi^2 + \text{h.c.}$	0 + 0 + 2 + 0	2
4 (1, 0)	$\phi^2 \phi^2 + \text{h.c.}$	0 + 0 + 2 + 0	2
Total		0 + 0 + 4 + 0	4

2

[Aguila, Bar-Shalom, Soni, Wudka, 2009]

Dimension-6

Dim-6 operators			
$N$ ( $n, \bar{n}$ )	Classes	$N_{\text{type}}$	$N_{\text{sm}}$
4 (2, 0)	$\psi^4 + \text{h.c.}$	4 + 2 + 0 + 2	14
	$F_L \psi^2 \phi + \text{h.c.}$	4 + 0 + 0 + 0	4
5 (1, 0)	$\psi^2 \phi^2 + \text{h.c.}$	10 + 2 + 0 + 0	12
	$\psi \psi^\dagger \phi^2 D$	3 + 0 + 0 + 0	3
6 (1, 0)	$\psi^2 \phi^3 + \text{h.c.}$	2 + 0 + 0 + 0	2
	Total	8	23 + 4 + 0 + 2

29

Dimension-7

$N$ ( $n, \bar{n}$ )	Classes	$N_{\text{sp}}$	$N_{\text{sm}}$
4 (3, 0)	$F_L^2 \psi^2 + \text{h.c.}$	0 + 0 + 5 + 0	6
	$F_L^2 \phi^2 + \text{h.c.}$	0 + 5 + 5 + 0	6
5 (2, 0)	$\phi^4 \psi^2 + \text{h.c.}$	0 + 4 + 20 + 0	24
	$F_L \psi \psi^\dagger \phi D + \text{h.c.}$	0 + 0 + 5 + 0	8
6 (1, 0)	$\psi^2 \phi^2 D^2 + \text{h.c.}$	0 + 0 + 4 + 0	6
	Total	18	0 + 10 + 56 + 0

[Bhattacharya, Wudka, 2016]

[Liao, Ma, 2017]

Dimension-8

[Li, Ren, Xiao, Yu, Zheng, 2021]

$N$ ( $n, \bar{n}$ )	Classes	$N_{\text{sp}}$	$N_{\text{sm}}$
4 (3, 1)	$\psi^4 D^2 + \text{h.c.}$	4 + 0 + 2 + 2	22
	$F_L \psi^2 \phi D^2 + \text{h.c.}$	4 + 0 + 0 + 0	8
(2, 2)	$F_L F_R \psi \psi^\dagger D$	3 + 0 + 0 + 0	3
	$\psi^2 \phi^{12} D^2$	10 + 2 + 0 + 0	24
5 (3, 0)	$F_L \psi^2 \phi^2 + \text{h.c.}$	4 + 0 + 0 + 0	4
	$\psi \psi^\dagger \phi^2 D^2$	3 + 0 + 0 + 0	4
6 (2, 1)	$F_L \psi^4 + \text{h.c.}$	10 + 4 + 0 + 2	50
	$F_L^2 \psi^2 \phi + \text{h.c.}$	8 + 0 + 0 + 0	12
(2, 1)	$F_L \psi^2 \phi^{12} + \text{h.c.}$	42 + 12 + 0 + 0	58
	$F_L^2 \phi^{12} \phi + \text{h.c.}$	8 + 0 + 0 + 0	8
(1, 1)	$\psi^3 \psi^\dagger \phi D + \text{h.c.}$	24 + 6 + 0 + 2	108
	$F_L \psi \psi^\dagger \phi^2 D + \text{h.c.}$	12 + 0 + 0 + 0	16
7 (1, 0)	$\psi^2 \phi^2 + \text{h.c.}$	2 + 0 + 0 + 0	12
	Total	31	167 + 30 + 2 + 10

323

Dimension-9

[Li, Ren, Xiao, Yu, Zheng, 2021]

$N$ ( $n, \bar{n}$ )	Classes	$N_{\text{sp}}$	$N_{\text{sm}}$
4 (4, 0)	$F_L^2 \psi^2 \phi^2 + \text{h.c.}$	0 + 6 + 0 + 0	12
	$F_L^2 F_R \psi^2 D^2 + \text{h.c.}$	0 + 6 + 0 + 0	6
(3, 1)	$F_L^2 \psi^{12} D^2 + \text{h.c.}$	0 + 6 + 0 + 0	6
	$F_L^2 \phi^{12} D^2 + \text{h.c.}$	0 + 6 + 0 + 0	6
(2, 2)	$\psi^2 \phi^{12} \phi + \text{h.c.}$	4 + 20 + 0 + 0	48
	$F_L \psi^2 \phi^2 D^2 + \text{h.c.}$	0 + 8 + 0 + 0	16
(1, 1)	$\psi^2 \phi^2 D^2 + \text{h.c.}$	0 + 1 + 0 + 0	8
	Total	18	0 + 10 + 56 + 0
5 (4, 0)	$F_L^4 \psi^2 + \text{h.c.}$	0 + 10 + 0 + 0	10
	$F_L^2 \psi^{12} + \text{h.c.}$	0 + 4 + 0 + 0	4
(3, 1)	$F_L^2 \psi^2 D + \text{h.c.}$	10 + 42 + 0 + 0	222
	$F_L^2 \psi \psi^\dagger \phi D + \text{h.c.}$	0 + 10 + 0 + 0	20
(2, 2)	$\psi^2 \phi^2 D^2 + \text{h.c.}$	9 + 10 + 0 + 1	190
	$F_L \psi^2 \phi^2 D^2 + \text{h.c.}$	0 + 8 + 0 + 0	40
(1, 1)	$F_L F_R \psi^2 + \text{h.c.}$	0 + 12 + 0 + 0	12
	$F_L \psi^2 \psi^\dagger D + \text{h.c.}$	10 + 12 + 0 + 0	160
(0, 1)	$F_L^2 \psi \psi^\dagger \phi D + \text{h.c.}$	0 + 10 + 0 + 0	20
	$\psi^2 \psi^\dagger \phi^2 D^2 + \text{h.c.}$	4 + 22 + 0 + 0	210
(0, 0)	$F_L \psi^2 \phi^2 D^2 + \text{h.c.}$	0 + 8 + 0 + 0	24
	$\psi \psi^\dagger \phi^2 D^2 + \text{h.c.}$	0 + 2 + 0 + 0	20
6 (3, 0)	$\psi^6 + \text{h.c.}$	0 + 10 + 0 + 2	100
	$F_L \psi^4 \phi + \text{h.c.}$	6 + 26 + 0 + 3	110
(2, 1)	$F_L^2 \psi^2 \phi^2 + \text{h.c.}$	0 + 12 + 0 + 3	15
	$\psi^4 \phi^2 D^2 + \text{h.c.}$	0 + 106 + 0 + 0	474
(1, 1)	$F_L^2 \psi^2 \phi^2 \phi + \text{h.c.}$	24 + 116 + 0 + 0	176
	$F_L^2 \psi \psi^\dagger \phi^2 D + \text{h.c.}$	0 + 10 + 0 + 3	13
(0, 1)	$\psi^2 \psi^\dagger \phi^2 D + \text{h.c.}$	10 + 14 + 0 + 0	268
	$F_L \psi^2 \phi^2 D^2 + \text{h.c.}$	0 + 8 + 0 + 0	32
(0, 0)	$\psi^2 \phi^2 D^2 + \text{h.c.}$	0 + 4 + 0 + 0	20
	Total	1358	0 + 10 + 56 + 0

1358

# Mathematica Code: ABC4EFT

## Amplitude Basis Construction for Effective Field Theory Automatic Basis Conversion for Effective Field Theory

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### Welcome to the HEPForge Project: ABC4EFT

This is the website for the Mathematica package: Amplitude Basis Construction for Effective Field Theory Package

This package has the following features:

- It provides a general procedure to construct the independent and complete operator bases for invariant effective field theory, given any kind of gauge symmetry and field content, up to any order.
- Various operator bases have been systematically constructed to emphasize different aspects of independence (y-basis), flavor relation (p-basis) and conserved quantum number (j-basis).
- It provides a systematic way to convert any operator into our on-shell amplitude basis and this can be easily done.

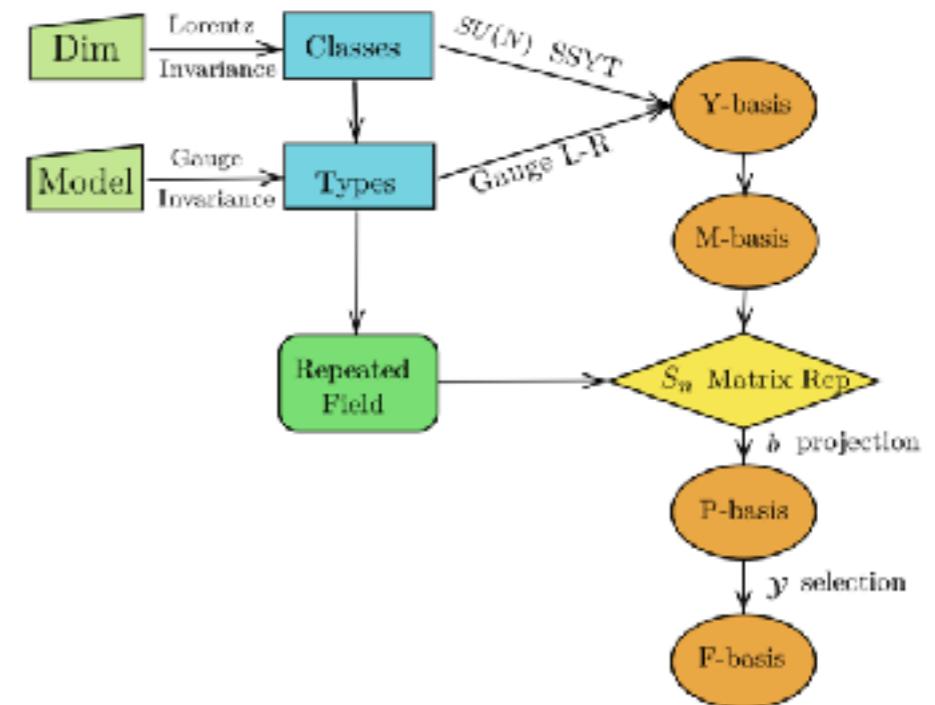
### Authors

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<https://abc4eft.hepforge.org/>

[ Li, Ren, Xiao, **Yu**, Zheng, 2201.04639 ]



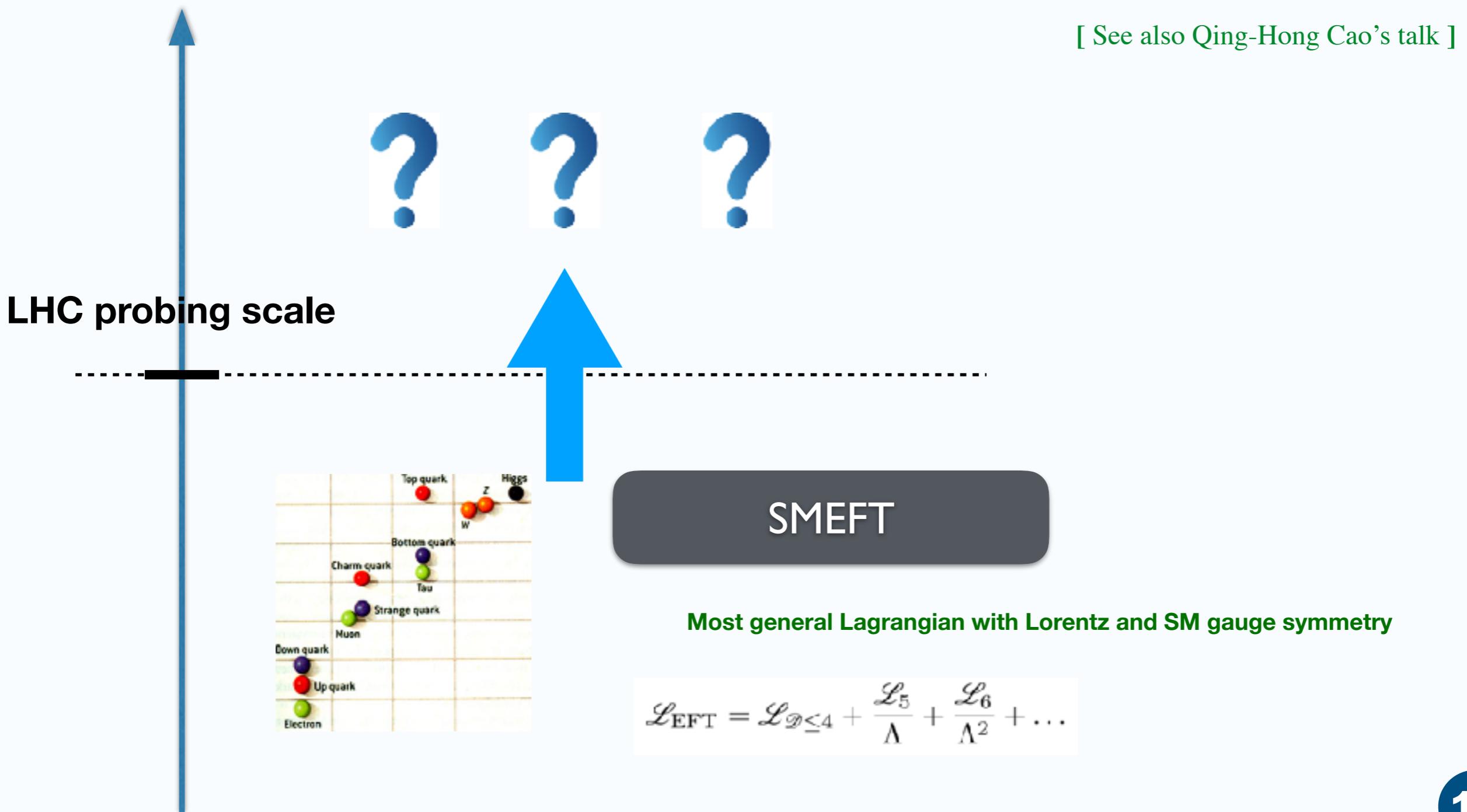
Fully Automatic

Dark matter EFT  
Sterile neutrino EFT  
Gravity EFT  
Axion EFT  
...

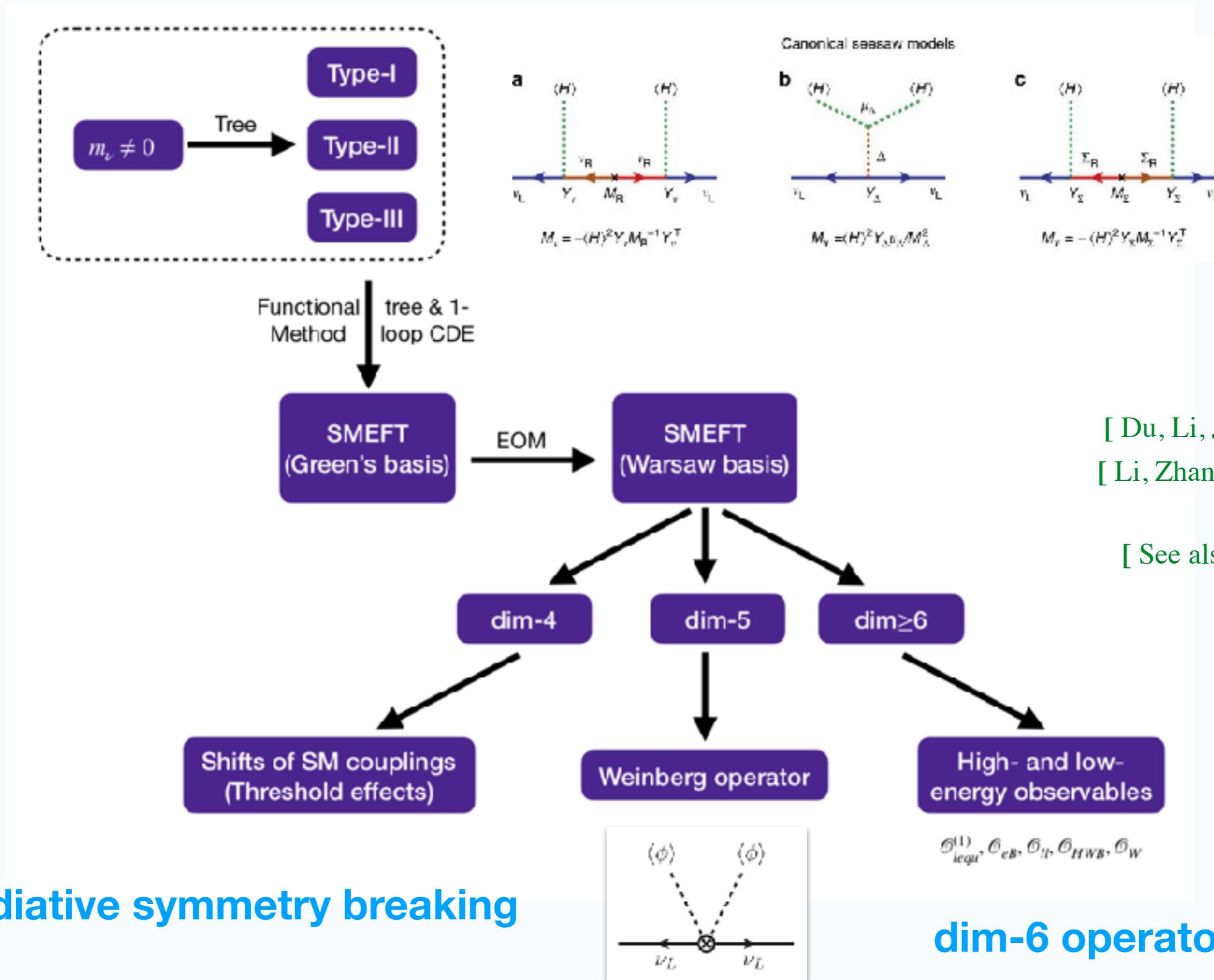
# Bottom-Up EFT

Given the effective operators, what kinds of UV for such operators?

**SMEFT Inverse Problem!**

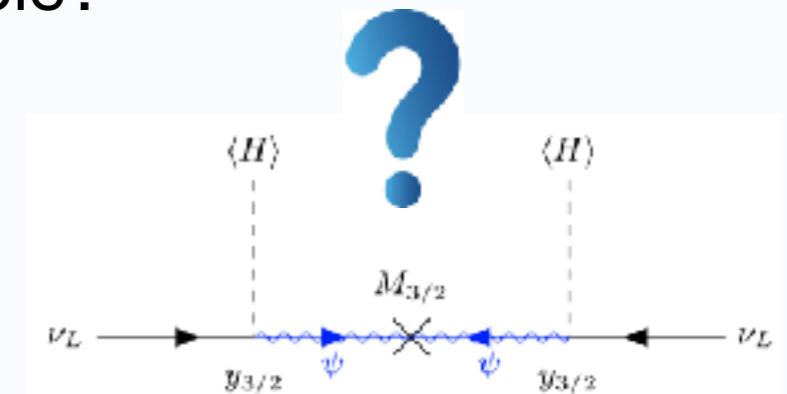
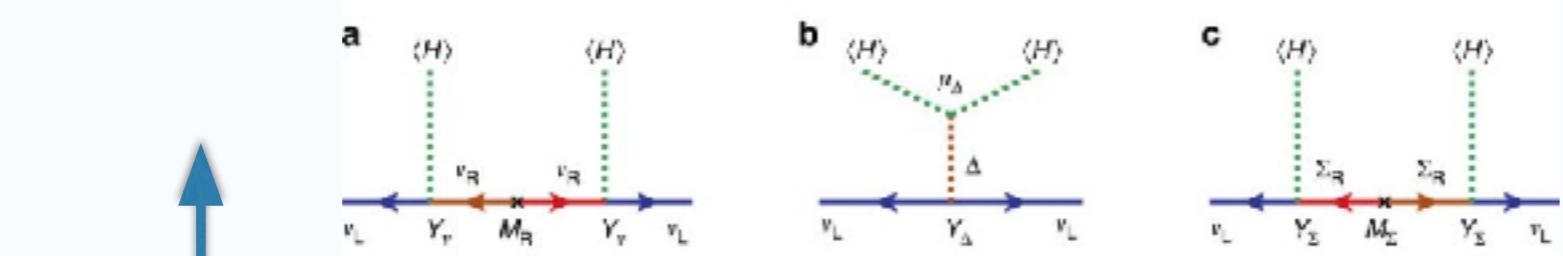


# Canonical Seesaw Models

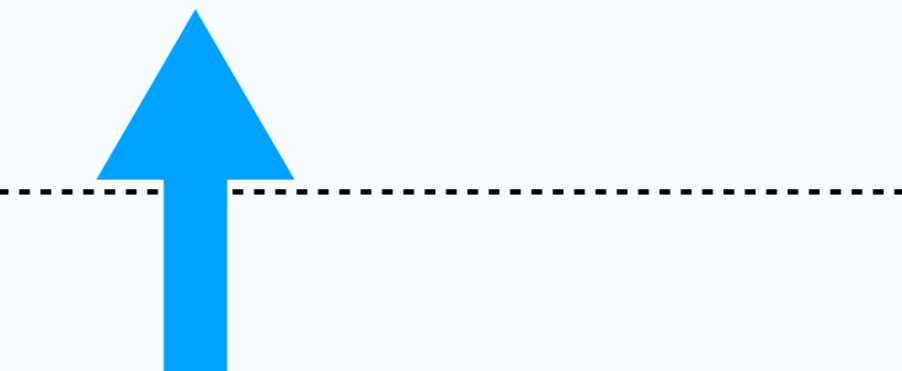


# Bottom-up: Type-3/2 Seesaw?

Whether additional seesaw (type-3/2 seesaw) is possible?



[ Demir, Karahan, Sargm, 2021 ]



SMEFT

$$\frac{1}{2} m_\nu \overline{\nu}_L^\nu \nu_L$$

LEFT

Angular momentum conservation not imposed!

# Complete Tree Seesaw Proved!

$$\mathcal{O}^S = (HL)(HL)$$

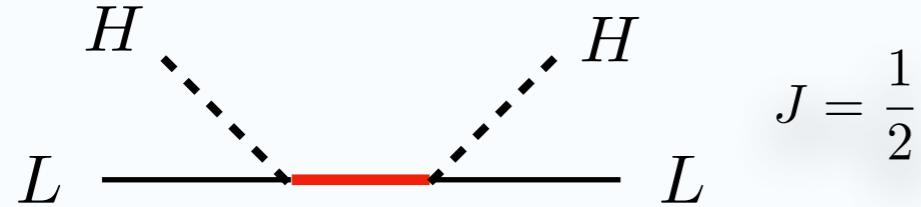
[ Li, Ni, Xiao, Yu, 2204.03660 ]

Generalized partial wave analysis for Poincare/Gauge Casimir

$$\mathbf{W}^2 \mathcal{B}^J = -s J(J+1) \mathcal{B}^J$$

$LH \rightarrow LH$  channel

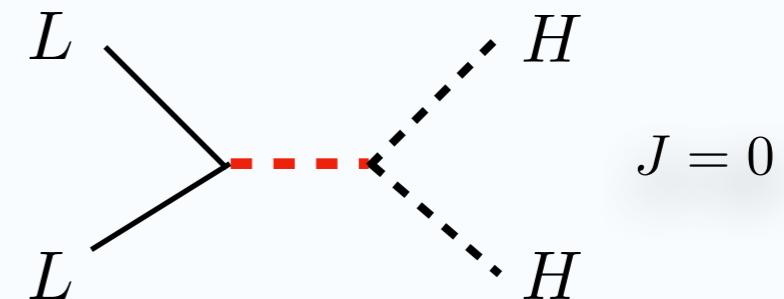
$$W_{\{1,3\}}^2 \mathcal{B}^y = -\frac{3}{4} s_{13} \langle 12 \rangle$$



Type-I and III: SU(2) **single and triplet**

$LL \rightarrow HH$  channel

$$W_{\{1,2\}}^2 \mathcal{B}^y = 0$$



Type-II: SU(2) **triplet**, or singlet (excluded by repeated field)

j-basis	Model
$\mathcal{O}_{HL \rightarrow HL}^{(1/2,1)} = \mathcal{O}^S + \mathcal{O}^A$	type I
$\mathcal{O}_{HL \rightarrow HL}^{(1/2,3)} = \mathcal{O}^S - 3\mathcal{O}^A$	type III

j-basis	Model
$\mathcal{O}_{HH \rightarrow LL}^{(0,1)} = \mathcal{O}^A$	N/A
$\mathcal{O}_{HH \rightarrow LL}^{(0,3)} = \mathcal{O}^S$	type II

$$\mathcal{O}^S = (HL)(HL), \quad \mathcal{O}^A = (HH)(LL)$$

# Genuine dim-7 Seesaw

[ Li, Ni, Xiao, Yu, 2204.03660 ]

Tree-level seesaw at dim-7: among 19 topologies, one genuine dim-7 seesaw

Topology	j-basis	Quantum numbers $\{J, R, Y\}$
	$O_{\{12 33 56\},1} = 2O_1^p - 4O_2^p$	$\{0, 3, -1\}, \{0, 3, 1\}, \{0, 3, 0\}$
	$O_{\{12 33 56\},2} = 2O_2^p + 4O_3^p$	$\{0, 3, -1\}, \{0, 1, 1\}, \{0, 3, 0\}$
	$O_{\{12 33 56\},3} = 12O_4^p$	$\{0, 1, -1\}, \{0, 3, 1\}, \{0, 3, 0\}$
	$O_{\{12 33 56\},4} = 4O_1^p + 4O_2^p$	$\{0, 3, -1\}, \{0, 3, 1\}, \{0, 1, 0\}$
	$O_{\{12 33 56\},5} = 2O_4^p + 4O_5^p$	$\{0, 1, -1\}, \{0, 1, 1\}, \{0, 1, 0\}$
	$O_{\{13 24 56\},1} = -O_2^p - 2O_3^p + 3O_4^p$	$\{\frac{1}{2}, 3, 0\}, \{\frac{1}{2}, 3, 0\}, \{0, 3, 0\}$
	$O_{\{13 24 56\},2} = -O_1^p + 3O_2^p + 2O_3^p + 3O_4^p$	$\{\frac{1}{2}, 3, 0\}, \{\frac{1}{2}, 1, 0\}, \{0, 3, 0\}$
	$O_{\{13 24 56\},3} = -O_1^p + O_2^p - 2O_3^p - 3O_4^p$	$\{\frac{1}{2}, 1, 0\}, \{\frac{1}{2}, 3, 0\}, \{0, 3, 0\}$
	$O_{\{13 24 56\},4} = -O_1^p - O_2^p + 3O_3^p + 6O_5^p$	$\{\frac{1}{2}, 3, 0\}, \{\frac{1}{2}, 3, 0\}, \{0, 1, 0\}$
	$O_{\{13 24 56\},5} = O_1^p + O_2^p + O_4^p + 2O_5^p$	$\{\frac{1}{2}, 1, 0\}, \{\frac{1}{2}, 1, 0\}, \{0, 1, 0\}$
	$O_{\{16 23 45\},1} = 2O_1^p - 2O_2^p - 2O_3^p + 6O_4^p + 6O_5^p$	$\{\frac{1}{2}, 3, -1\}, \{\frac{1}{2}, 3, 0\}, \{0, 3, 1\}$
	$O_{\{16 23 45\},2} = -2O_1^p - O_2^p - O_3^p + 3O_4^p + 3O_5^p$	$\{\frac{1}{2}, 3, -1\}, \{\frac{1}{2}, 1, 0\}, \{0, 3, 1\}$
	$O_{\{16 23 45\},3} = 3O_2^p + 3O_3^p + 3O_4^p + 3O_5^p$	$\{\frac{1}{2}, 1, -1\}, \{\frac{1}{2}, 3, 0\}, \{0, 3, 1\}$
	$O_{\{16 23 45\},4} = O_1^p - O_2^p - 3O_4^p + 3O_5^p$	$\{\frac{1}{2}, 3, -1\}, \{\frac{1}{2}, 3, 0\}, \{0, 1, 1\}$
	$O_{\{16 23 45\},5} = O_2^p - O_3^p + O_4^p - O_5^p$	$\{\frac{1}{2}, 1, -1\}, \{\frac{1}{2}, 1, 0\}, \{0, 1, 1\}$
	$O_{\{12 125 34\},1} = O_1^p + 4O_2^p$	$\{0, 3, -1\}, \{0, 4, -\frac{1}{2}\}, \{0, 3, 1\}$
	$O_{\{12 125 34\},2} = -8O_1^p + 4O_2^p$	$\{0, 3, -1\}, \{0, 2, -\frac{1}{2}\}, \{0, 3, 1\}$
	$O_{\{12 125 34\},3} = -12O_4^p$	$\{0, 1, -1\}, \{0, 2, -\frac{1}{2}\}, \{0, 3, 1\}$
	$O_{\{12 125 34\},4} = -2O_2^p - 4O_3^p$	$\{0, 3, -1\}, \{0, 2, -\frac{1}{2}\}, \{0, 1, 1\}$
	$O_{\{12 125 34\},5} = -2O_4^p - 4O_5^p$	$\{0, 1, -1\}, \{0, 2, -\frac{1}{2}\}, \{0, 1, 1\}$
	$O_{\{12 126 34\},1} = 3O_1^p$	$\{0, 3, -1\}, \{0, 4, -\frac{3}{2}\}, \{0, 3, 1\}$
	$O_{\{12 126 34\},2} = 12O_2^p$	$\{0, 3, -1\}, \{0, 2, -\frac{3}{2}\}, \{0, 3, 1\}$
	$O_{\{12 126 34\},3} = -12O_4^p$	$\{0, 1, -1\}, \{0, 2, -\frac{3}{2}\}, \{0, 3, 1\}$
	$O_{\{12 126 34\},4} = -2O_2^p - 4O_3^p$	$\{0, 3, -1\}, \{0, 2, -\frac{3}{2}\}, \{0, 1, 1\}$
	$O_{\{12 126 34\},5} = -2O_4^p - 4O_5^p$	$\{0, 1, -1\}, \{0, 2, -\frac{3}{2}\}, \{0, 1, 1\}$
	$O_{\{12 124 36\},1} = -O_1^p - 4O_3^p$	$\{0, 3, -1\}, \{0, 4, -\frac{1}{2}\}, \{0, 3, 0\}$
	$O_{\{12 124 36\},2} = 2O_1^p + 6O_2^p + 2O_5^p$	$\{0, 3, -1\}, \{0, 2, -\frac{1}{2}\}, \{0, 3, 0\}$
	$O_{\{12 124 36\},3} = -6O_4^p - 6O_5^p$	$\{0, 1, -1\}, \{0, 2, -\frac{1}{2}\}, \{0, 3, 0\}$
	$O_{\{12 124 36\},4} = -2O_1^p + 2O_2^p + 2O_3^p$	$\{0, 3, -1\}, \{0, 2, -\frac{1}{2}\}, \{0, 1, 0\}$
	$O_{\{12 124 36\},5} = -2O_4^p + 2O_5^p$	$\{0, 1, -1\}, \{0, 2, -\frac{1}{2}\}, \{0, 1, 0\}$
	$O_{\{13 135 24\},1} = O_1^p - 2O_3^p - 6O_5^p$	$\{\frac{1}{2}, 3, 0\}, \{\frac{1}{2}, 4, \frac{1}{2}\}, \{\frac{1}{2}, 3, 0\}$
	$O_{\{13 135 24\},2} = -O_1^p - 3O_2^p - 4O_3^p + 9O_4^p + 6O_5^p$	$\{\frac{1}{2}, 3, 0\}, \{\frac{1}{2}, 2, \frac{1}{2}\}, \{\frac{1}{2}, 3, 0\}$
	$O_{\{13 135 24\},3} = O_1^p - O_2^p + 2O_3^p + 3O_4^p$	$\{\frac{1}{2}, 1, 0\}, \{\frac{1}{2}, 2, \frac{1}{2}\}, \{\frac{1}{2}, 3, 0\}$
	$O_{\{13 135 24\},4} = O_1^p - 3O_2^p - 2O_3^p - 3O_5^p$	$\{\frac{1}{2}, 3, 0\}, \{\frac{1}{2}, 2, \frac{1}{2}\}, \{\frac{1}{2}, 1, 0\}$
	$O_{\{13 135 24\},5} = O_1^p + O_2^p + O_4^p + 2O_5^p$	$\{\frac{1}{2}, 1, 0\}, \{\frac{1}{2}, 2, \frac{1}{2}\}, \{\frac{1}{2}, 1, 0\}$
	$O_{\{13 146 23\},1} = -2O_1^p + 4O_3^p - 12O_5^p$	$\{\frac{1}{2}, 3, -1\}, \{\frac{1}{2}, 4, -\frac{1}{2}\}, \{\frac{1}{2}, 3, 0\}$
	$O_{\{13 146 23\},2} = 2O_1^p - 3O_2^p - O_3^p + 9O_4^p + 3O_5^p$	$\{\frac{1}{2}, 3, -1\}, \{\frac{1}{2}, 2, -\frac{1}{2}\}, \{\frac{1}{2}, 3, 0\}$
	$O_{\{13 146 23\},3} = 3O_2^p + 3O_3^p + 3O_4^p + 3O_5^p$	$\{\frac{1}{2}, 1, -1\}, \{\frac{1}{2}, 2, -\frac{1}{2}\}, \{\frac{1}{2}, 3, 0\}$
	$O_{\{13 146 23\},4} = -2O_1^p + O_2^p + O_3^p - 3O_4^p - 3O_5^p$	$\{\frac{1}{2}, 3, -1\}, \{\frac{1}{2}, 2, -\frac{1}{2}\}, \{\frac{1}{2}, 1, 0\}$
	$O_{\{13 146 23\},5} = -O_2^p + O_3^p - O_4^p + O_5^p$	$\{\frac{1}{2}, 1, -1\}, \{\frac{1}{2}, 2, -\frac{1}{2}\}, \{\frac{1}{2}, 1, 0\}$

	$O_{\{13 123 45\},1} = O_1^p - 4O_2^p - 4O_3^p$	$\{\frac{1}{2}, 3, 0\}, \{0, 4, -\frac{1}{2}\}, \{0, 3, 1\}$	$\{1, 3, 0\}, \{10, 4, -\frac{1}{2}\}$
	$O_{\{13 123 45\},2} = 2O_1^p + O_2^p + O_3^p - 9O_4^p - 9O_5^p$	$\{\frac{1}{2}, 3, 0\}, \{0, 2, -\frac{1}{2}\}, \{0, 3, 1\}$	$\{1, 3, 0\}, \{10, 2, -\frac{1}{2}\}$
	$O_{\{13 123 45\},3} = 2O_1^p + O_2^p + O_3^p + 3O_4^p + 3O_5^p$	$\{\frac{1}{2}, 1, 0\}, \{0, 2, -\frac{1}{2}\}, \{0, 3, 1\}$	$\{1, 1, 0\}, \{10, 2, -\frac{1}{2}\}$
	$O_{\{13 123 45\},4} = O_2^p - O_3^p + 3O_4^p - 3O_5^p$	$\{\frac{1}{2}, 3, 0\}, \{0, 2, -\frac{1}{2}\}, \{0, 1, 1\}$	$\{0, 3, -1\}, \{10, 4, -\frac{1}{2}\}$
	$O_{\{13 123 45\},5} = -O_2^p + O_3^p + O_4^p - O_5^p$	$\{\frac{1}{2}, 1, 0\}, \{0, 2, -\frac{1}{2}\}, \{0, 1, 1\}$	$\{0, 3, -1\}, \{10, 2, -\frac{1}{2}\}$
	$O_{\{13 123 46\},1} = O_1^p - 4O_2^p - 4O_3^p$	$\{\frac{1}{2}, 3, 0\}, \{0, 4, -\frac{1}{2}\}, \{0, 3, 1\}$	$\{1, 3, 0\}, \{10, 4, -\frac{1}{2}\}$
	$O_{\{13 123 46\},2} = O_1^p + 2O_2^p - O_3^p - 9O_5^p$	$\{\frac{1}{2}, 3, 0\}, \{0, 2, -\frac{1}{2}\}, \{0, 3, 1\}$	$\{0, 1, -1\}, \{10, 2, -\frac{1}{2}\}$
	$O_{\{13 123 46\},3} = -O_1^p - 2O_2^p + O_3^p - 3O_5^p$	$\{\frac{1}{2}, 1, 0\}, \{0, 2, -\frac{1}{2}\}, \{0, 3, 1\}$	$\{0, 3, -1\}, \{10, 4, -\frac{1}{2}\}$
	$O_{\{13 123 46\},4} = -O_1^p - O_3^p + 6O_4^p + 3O_5^p$	$\{\frac{1}{2}, 3, 0\}, \{0, 4, -\frac{1}{2}\}, \{0, 1, 1\}$	$\{0, 3, -1\}, \{10, 2, -\frac{1}{2}\}$
	$O_{\{13 123 46\},5} = -O_1^p - O_3^p - 2O_4^p - O_5^p$	$\{\frac{1}{2}, 1, 0\}, \{0, 2, -\frac{1}{2}\}, \{0, 1, 1\}$	$\{0, 1, -1\}, \{10, 2, -\frac{1}{2}\}$
	$O_{\{16 126 34\},1} = 6O_1^p$	$\{\frac{1}{2}, 3, -1\}, \{0, 4, -\frac{3}{2}\}, \{0, 3, 1\}$	$[ Bonnet, Hernandez, Ota, Winter, 2009 ]$
	$O_{\{16 126 34\},2} = -3O_2^p + 9O_4^p$	$\{\frac{1}{2}, 3, -1\}, \{0, 4, -\frac{3}{2}\}, \{0, 3, 1\}$	
	$O_{\{16 126 34\},3} = -3O_2^p - 3O_4^p$	$\{\frac{1}{2}, 3, -1\}, \{0, 4, -\frac{3}{2}\}, \{0, 3, 1\}$	
	$O_{\{16 126 34\},4} = O_2^p - 2O_3^p + 3O_4^p + 6O_5^p$	$\{\frac{1}{2}, 3, -1\}, \{0, 4, -\frac{3}{2}\}, \{0, 3, 1\}$	
	$O_{\{16 126 34\},5} = O_2^p + 2O_3^p + O_4^p + 2O_5^p$	$\{\frac{1}{2}, 3, -1\}, \{0, 4, -\frac{3}{2}\}, \{0, 3, 1\}$	
	$O_{\{23 235 46\},1} = O_1^p - 2O_2^p + 6O_5^p$	$\{\frac{1}{2}, 3, 0\}, \{\frac{1}{2}, 4, \frac{1}{2}\}, \{0, 3, 0\}$	
	$O_{\{23 235 46\},2} = O_1^p - 6O_2^p - 5O_3^p - 3O_4^p$	$\{\frac{1}{2}, 3, 0\}, \{\frac{1}{2}, 2, -\frac{1}{2}\}, \{0, 3, 1\}$	
	$O_{\{23 235 46\},3} = O_1^p + 2O_2^p - O_3^p - 3O_5^p$	$\{\frac{1}{2}, 1, 0\}, \{\frac{1}{2}, 2, \frac{1}{2}\}, \{0, 3, 0\}$	
	$O_{\{23 235 46\},4} = -O_1^p - O_3^p - 6O_4^p - 3O_5^p$	$\{\frac{1}{2}, 3, 0\}, \{\frac{1}{2}, 2, \frac{1}{2}\}, \{0, 1, 1\}$	
	$O_{\{23 235 46\},5} = -O_1^p - O_3^p + 2O_4^p + O_5^p$	$\{\frac{1}{2}, 1, 0\}, \{\frac{1}{2}, 2, \frac{1}{2}\}, \{0, 1, 1\}$	
	$O_{\{13 136 45\},1} = O_1^p + 2O$		

# Complete Dim-6 UV Resonances

[ Li, Ni, Xiao, Yu, 2204.03660 ]

Scalar		Vector		
$(SU(3)_c, SU(2)_2, U(1)_y)$		$(SU(3)_c, SU(2)_2, U(1)_y)$		
$S1 (1, 1, 0)$	$B_L H H^\dagger D^2 H^2 H^{12} d_C H H^{12} Q[(F11), (F8)] e_C H H^{12} L[(F3), (F2)]$ $G_L^2 H H^\dagger H^2 H^\dagger Q u_C [(S4), (F11), (F9)] H H^\dagger W_L^2$ $H^3 H^{13} [(S6), (S2), (S5), (S4, S6), (S2, S4), (S4, S5), (S4)]$ $e_C H H^{12} L \quad d_C H H^{12} Q \quad H^2 H^\dagger Q u_C$	$V1 (1, 1, 0)$	$d_C^2 d_C^{\dagger 2} d_C d_C^\dagger e_C e_C^\dagger e_C^2 e_C^{\dagger 2} D d_C d_C^\dagger H H^\dagger$ $D e_C e_C^\dagger H H^\dagger D^2 H^2 H^{12} d_C d_C^\dagger L L^\dagger e_C e_C^\dagger L L^\dagger$ $D H H^\dagger L L^\dagger L^2 L^{\dagger 2} d_C d_C^\dagger Q Q^\dagger e_C e_C^\dagger Q Q^\dagger$ $D H H^\dagger Q Q^\dagger L L^\dagger Q Q^\dagger Q^2 Q^{\dagger 2} d_C d_C^\dagger u_C u_C^\dagger$ $e_C e_C^\dagger u_C u_C^\dagger D H H^\dagger u_C u_C^\dagger L L^\dagger u_C u_C^\dagger Q Q^\dagger u_C u_C^\dagger$ $d_C H H^{12} Q \quad e_C H H^{12} L \quad H^2 H^\dagger Q u_C$ $e_C H H^{12} L \quad d_C H H^{12} Q \quad H^2 H^\dagger Q u_C$	
$S2 (1, 1, 1)$	$d_C H H^{12} Q [(S4), (F10), (F9)] e_C H H^{12} L [(S4), (F4), (F1)]$ $H^2 H^\dagger Q u_C [(F8), (F12)] L^2 L^{\dagger 2}$ $H^3 H^{13} [(S4), (S5), (S5, S6), (S1), (S4, S5), (S1, S4), (S5, S6), (S4, S6)]$	$V2 (1, 1, 1)$	$D^2 E^2 H^{12} D d_C H^{12} u_C^\dagger d_C d_C^\dagger u_C u_C^\dagger$ $e_C H H^{12} L \quad d_C H H^{12} Q \quad H^2 H^\dagger Q u_C$ $d_C H H^{12} Q$	
$S3 (1, 1, 2)$	$e_C^2 e_C^{\dagger 2}$	$V3 (1, 2, \frac{3}{2})$	$e_C e_C^\dagger L L^\dagger$	
$S4 (1, 2, \frac{1}{2})$	$d_C^2 e_C L Q^\dagger d_C H H^{12} Q [(S6), (S2)] e_C H H^{12} L [(S6), (S2)]$ $H^2 H^\dagger Q u_C H^2 H^\dagger Q u_C [(S5), (S1)] Q Q^\dagger u_C u_C^\dagger$ $H^3 H^{13} [(S6), (S2), (S5, S6), (S2, S5), (S1, S6), (S1, S2), (S2, S6), (S5), (S1, S5), (S1)]$	$V4 (1, 3, 0)$	$D^2 H^2 H^{12} D H H^\dagger L L^\dagger L^2 L^{\dagger 2} D H H^\dagger Q Q^\dagger$ $L L^\dagger Q Q^\dagger Q^2 Q^{\dagger 2}$ $e_C H H^{12} L \quad d_C H H^{12} Q \quad H^2 H^\dagger Q u_C$ $e_C H H^{12} L$	
$S5 (1, 3, 0)$	$B_L H H^\dagger W_L D^2 H^2 H^{12} d_C H H^{12} Q [(F11), (F13)]$ $e_C H H^{12} L [(F3), (F6)] H^2 H^\dagger Q u_C [(S4), (F11), (F14)] H H^\dagger W_L^2$ $H^3 H^{13} [(S7), (S6), (S2, S6), (S1), (S1)]$ $e_C H H^{12} L \quad d_C H H^{12} Q$	$Fermion$	$V5 (3, 1, \frac{2}{3})$ $d_C^2 e_C L Q^\dagger$ $V6 (3, 1, \frac{5}{3})$ $e_C e_C^\dagger u_C u_C^\dagger$	
$S6 (1, 3, 1)$	$d_C H H^{12} Q [(S4), (F10), (F14)]$ $H^2 H^\dagger Q u_C [(F1)]$ $H^3 H^{13} [(S7), (S4), (S1), (S5, S7), (S4, S5), (S1)]$	$F1 (1, 1, 0)$ $F2 (1, 1, 1)$	$D H H^\dagger L L^\dagger e_C H H^{12} L [(F3), (F1)]$ $B_L e_C H^\dagger L D H H^\dagger L L^\dagger e_C H H$ $e_C H H^{12} L$	$V7 (3, 2, -\frac{5}{6})$ $d_C d_C^\dagger L L^\dagger d_C^2 e_C L Q^\dagger e_C e_C^\dagger Q Q^\dagger d_C L^\dagger Q^\dagger u_C$ $e_C Q^{\dagger 2} u_C Q Q^\dagger u_C u_C^\dagger$
$S7 (1, 4, \frac{1}{2})$	$H^3 H^{13} [(S1)]$	$F3 (1, 2, \frac{1}{2})$	$B_L e_C H^\dagger L e_C H H^{12} L [(F5), (F1)]$	$V8 (3, 2, \frac{1}{6})$ $d_C d_C^\dagger Q Q^\dagger d_C L^\dagger Q^\dagger u_C L L^\dagger u_C u_C^\dagger$ $L L^\dagger Q Q^\dagger$
$S8 (1, 4, \frac{3}{2})$	$H^3$	$F4 (1, 2, \frac{3}{2})$	$D e_C e_C^\dagger H H^\dagger e_C H H^{12} L [(F6), (F2)]$	$V9 (3, 3, \frac{2}{3})$ $V10 (6, 2, -\frac{1}{6})$ $d_C d_C^\dagger Q Q^\dagger$
$S9 (3, 1, -\frac{4}{3})$		$F5 (1, 3, 0)$	$D H H^\dagger L L^\dagger e_C H H^{12} L [(F3), (F1)]$	$V11 (6, 2, \frac{5}{6})$ $V12 (8, 1, 0)$ $d_C^2 d_C^{\dagger 2} d_C d_C^\dagger Q Q^\dagger Q Q^\dagger u_C u_C^\dagger u_C^2 u_C^{\dagger 2}$
$S10 (3, 1, -\frac{1}{3})$	$Q^2 Q^{\dagger 2} e_C L Q u_C$	$F6 (1, 3, 1)$	$e_C H^\dagger L W_L e_C H H^{12} L [(F1), (F1)]$	$V13 (8, 1, 1)$ $d_C d_C^\dagger u_C u_C^\dagger$
$S11 (3, 1, \frac{2}{3})$		$F8 (3, 1, -\frac{1}{3})$	$B_L d_C H^\dagger Q d_C G_L H^\dagger Q D H H^\dagger Q Q^\dagger$	$V14 (8, 3, 0)$ $Q^2 Q^{\dagger 2}$
$S12 (3, 2, \frac{1}{6})$		$F9 (3, 1, \frac{2}{3})$	$D H H^\dagger Q Q^\dagger B_L H Q u_C G_L H Q u_C d_C H H^{12} Q [(F11), (S2)]$ $H^2 H^\dagger Q u_C$	
$S13 (3, 2, \frac{7}{6})$	$L$	$F10 (3, 2, -\frac{5}{6})$	$D d_C d_C^\dagger H H^\dagger d_C H H^{12} Q [(F13), (F8), (S6), (S2)]$ $d_C H H^{12} Q$	
$S14 (3, 3, -\frac{1}{3})$		$F11 (3, 2, \frac{1}{6})$	$B_L d_C H^\dagger Q B_L H Q u_C G_L H Q u_C D H H^\dagger u_C u_C^\dagger$ $d_C H H^{12} Q [(F14), (F9), (F13), (F8), (S5), (S1)]$ $H^2 H^\dagger Q u_C [(F14), (F9), (F13), (F8), (S5), (S1)]$	
$S15 (6, 1, -\frac{2}{3})$		$F12 (3, 2, \frac{7}{6})$	$D H H^\dagger u_C u_C^\dagger H^2 H^\dagger Q u_C [(F14), (F9), (S6), (S2)]$ $H^2 H^\dagger Q u_C$	
$S16 (6, 1, \frac{1}{3})$	$d_C Q^2 u$			
$S17 (6, 1, \frac{4}{3})$				
$S18 (6, 3, \frac{1}{3})$		$F13 (3, 3, -\frac{1}{3})$	$d_C H^\dagger Q W_L d_C H H^{12} Q [(F10), (F11), (S5)]$ $H^2 H^\dagger Q u_C$	
$S19 (8, 2, \frac{1}{2})$	$Q$	$F14 (3, 3, \frac{2}{3})$	$H Q u_C W_L d_C H H^{12} Q [(F11), (S6)]$ $H^2 H^\dagger Q$	

New LHC searches!

[ de Blas, Criado,  
Perez-Victoria, Santiago, 2017]

# Complete Dim-7 UV Resonances

Scalar		Vector		
$(SU(3)_c, SU(2)_2, U(1)_y)$		$(SU(3)_c, SU(2)_2, U(1)_y)$		
$S1 (1, 1, 0)$	$H^3 H^\dagger L^2 [(S6), (S2), (F5), (F1), (S4, S6), (S2, S4), (S4, F7), (S4, F1), (F3, F5), (F1, F3), (S6, F3), (S2, F3)]$	$V2 (\mathbf{1}, \mathbf{1}, 1)$	$D d_C L^2 u_C^\dagger$	$D^2 H^2 L^2$
$S2 (1, 1, 1)$	$D^2 H^2 L^2 - e_C H L^3 [(S4), (F4), (F1)] - d_C H L^2 Q [(S4), (F10), (F9)]$ $H L^2 Q^\dagger u_C^\dagger [(S4), (F8), (F12)]$ $D e_C H^{13} L^\dagger [(F1), (F3), (V3)]$ $H^3 H^\dagger L^2 [(F1, F3), (S5, S6), (S1), (F5, F6), (F1, F2), (S4, S6), (S4), (S5, S6), (S5), (S4, S5), (S1, S4), (S4, F5), (S4, F1), (F3, F5), (S5, F6), (S5, F2), (F3, F6), (F2, F3), (S5, F3), (S1, F3)]$ $H^2 L^2 W_L \quad B_L H^2 L^2 \quad e_C H L^3$ $H L^2 Q^\dagger u_C^\dagger \quad d_C H L^2 Q \quad D e_C^\dagger H^3 L$	$V3 (\mathbf{1}, \mathbf{2}, \frac{3}{2})$	$D e_C H^{13} L^\dagger$	$d_C e_C^\dagger H L u_C^\dagger [(F10), (F12)]$
$S4 (1, 2, \frac{1}{2})$	$H^3 H^\dagger L^2 [(S6), (S2, S6), (S2), (S5, S6), (S2, S5), (S1, S6), (S1, S2), (S6, F5), (S6, F1), (S2, F5), (S2, F1), (S5, F5), (S5, F1), (S1, F5), (S1, F1)]$	$V5 (\mathbf{1}, \mathbf{3}, 1)$	$D^2 H^2 L^2$	$D e_C H^{13} L^\dagger [(F3), (V3), (F5)]$
$S5 (1, 3, 0)$	$H^3 H^\dagger L^2 [(S6), (S2, S6), (F5)]$ $(S2, S4), (S7, F5), (S4, F5), (F1, F3), (S6, F7),$	$Fermion$	$D d_C^2 e_C^\dagger$	$H^2 L^2 W_L \quad B_L H^2 L^2 \quad e_C H L^3$
$S6 (1, 3, 1)$	$D^2 H^2 L^2 - e_C H L^3 [(S4), (F4), (F1)]$ $H L^2 Q^\dagger u_C^\dagger [(S4), (F3), (F1)]$ $D e_C H^{13} L^\dagger [(F5), (F3), (F1)]$ $H^3 H^\dagger L^2 [(F3, F5), (S5), (S1), (S2, S7), (S4), (S2, S4), (S8), (S5), (S2, S5), (S4, F1), (F5, F7), (F1, F3), (S8, F6), (F2, F3), (S5, F7)]$ $H^2 L^2 W_L \quad B_L H^2 L^2 \quad e_C H L^3$ $H L^2 Q^\dagger u_C^\dagger \quad d_C H L^2 Q \quad D e_C^\dagger H^2 L$	$F1 (1, 1, 0)$	$D^2 H^2 L^2 \quad e_C H L^3 [(S4), (S2)]$	$d_C H L^2 Q [(S4), (S10), (S12)]$
$S7 (1, 4, \frac{1}{2})$	$H^3 H^\dagger L^2 [(S6), (S5, S1)]$	$F2 (1, 1, 1)$	$H L^2 Q^\dagger u_C^\dagger [(S4), (V5), (V8)]$	$D e_C H^{13} L^\dagger [(S2), (F3), (V2)]$
$S8 (1, 4, \frac{3}{2})$	$H^3 H^\dagger L^2 [(S6), (S5, S1)]$	$F3 (1, 2, \frac{1}{2})$	$D e_C^2 H L u_C^\dagger [(S11), (S10)]$	$d_C e_C^\dagger H L u_C^\dagger [(S10), (V5)] \quad d_C H L Q^{12} [(S10), (V8)]$
$S10 (3, 1, -\frac{1}{3})$	$d_C^2 H L u_C^\dagger [(S12), (F10), (F1)]$	$F4 (1, 2, \frac{3}{2})$	$H^2 L^2 W_L [(F5)]$	$H^3 H^\dagger L^2 [(S2, F3), (S5, F5), (S1), (S6, F6), (S2, F2), (F5, F5), (F3), (S4, S6), (S2, S4), (S5, F3), (S4, S5), (S1, S4), (F3, F6), (F2, F3), (S5, F3), (S1, F3)]$ $H^2 L^2 W_L \quad B_L H^2 L^2 \quad e_C H L^3$ $H L^2 Q^\dagger u_C^\dagger \quad d_C H L^2 Q \quad D e_C^\dagger H^2 L$
$S11 (3, 1, \frac{2}{3})$	$d_C^3 H^\dagger L [(S12), (F11), (F2)]$	$F5 (1, 3, 0)$	$d_C^3 H^\dagger L [(S11), (F11), (F2)]$	$d_C^3 H^\dagger L [(S11), (F11), (F2)]$
$S12 (3, 2, \frac{1}{6})$	$d_C^3 H^\dagger L [(S11), (F11)] \quad d_C^2 I$		$d_C^2 H^2 L^2$	$D e_C H^{13} L^\dagger [(S6), (F3), (V5)] \quad d_C H L Q^{12} [(S14), (V8)]$
$S13 (3, 2, \frac{7}{6})$	$d_C^2 H L u_C^\dagger [(S11), (F10)]$	$F6 (1, 3, 1)$	$H^2 L^2 W_L [(F7), (F1)]$	$H^2 L^2 W_L \quad B_L H^2 L^2 \quad e_C H L^3$
$S14 (3, 3, -\frac{1}{3})$	$d_C H L^2 Q [(S12), (F10), (F5)]$	$F7 (1, 4, \frac{1}{2})$	$H^3 H^\dagger L^2 [(S5, F5), (S6, F1), (S2, F5), (F5, F7), (F3, F5), (F1, F3), (S6, S8), (S5, S6), (S2, S5), (S5, F7), (S6, F3), (S2, F3)]$	$H^2 L^2 W_L [(F5), (S6)] \quad H^3 H^\dagger L^2 [(F5), (S6), (F5), (F5, F6), (S6, F5), (S5, S6)]$
		$F8 (3, 1, -\frac{1}{2})$	$H L^2 Q^\dagger u_C^\dagger [(S2), (V8)]$	$d_C H L Q^{12} [(V8), (S12), (V5)] \quad d_C^2 e_C^\dagger H Q^\dagger [(V5), (S11)]$
		$F9 (3, 1, \frac{2}{3})$	$d_C H L^2 Q [(S12), (S2)]$	
		$F10 (3, 2, -\frac{5}{6})$	$d_C^2 H L u_C^\dagger [(S12), (S16), (S13)]$	$d_C H L^2 Q [(S10), (S6), (S16), (S13)] \quad d_C e_C^\dagger H L u_C^\dagger [(S10), (V3), (V8)] \quad d_C H L Q^{12} [(S10), (S14), (S16)]$
		$F11 (3, 2, \frac{1}{6})$	$d_C^3 H^\dagger L [(S11), (S12)]$	$d_C^3 H^\dagger L [(S11), (S12)] \quad d_C^2 H L u_C^\dagger [(S11), (S12)]$
		$F12 (3, 2, \frac{2}{3})$	$H L^2 Q^\dagger u_C^\dagger [(S6), (S2), (V9), (V5)]$	$H L^2 Q^\dagger u_C^\dagger [(S6), (S2), (V9), (V5)] \quad d_C e_C^\dagger H L u_C^\dagger [(V5), (S12), (V3)]$
		$F13 (3, 3, -\frac{1}{3})$	$H L^2 Q^\dagger u_C^\dagger [(S6), (V9)]$	$H L^2 Q^\dagger u_C^\dagger [(S6), (V9)] \quad d_C H L Q^{12} [(V8), (S12), (V9)]$
		$F14 (3, 3, \frac{2}{3})$	$d_C H L^2 Q [(S12), (S6)]$	

[ Li, Ni, Xiao, Yu, 2204.03660 ]

More LHC searches!

# Complete Dim-8 UV Resonances

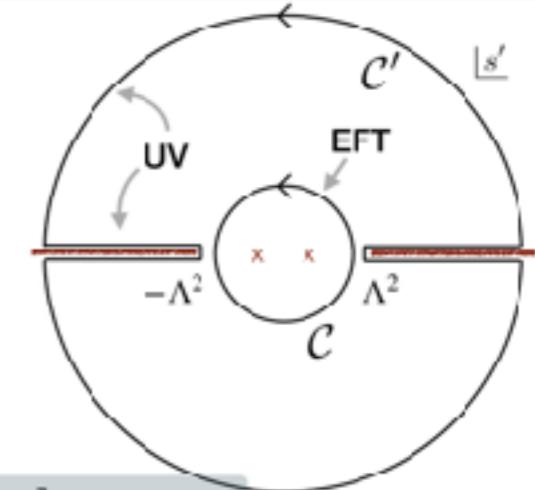
[ Li, Ni, Xiao, Yu, in preparation ]

Type	$\mathcal{O}_1^F = \frac{1}{4}\mathcal{Y}[\square_H]\mathcal{Y}[\square_{H^\dagger}]H_i H_j (D_\mu D_\nu H^{\dagger i})(D^\mu D^\nu H^{\dagger j})$ ,
$\mathcal{O}_2^F$	$= \frac{1}{4}\mathcal{Y}[\square_H]\mathcal{Y}[\square_{H^\dagger}]H^{\dagger i} H_i (D_\mu D_\nu H_j)(D^\mu D^\nu H^{\dagger j})$ ,
$\mathcal{O}_3^F$	$= \frac{1}{4}\mathcal{Y}[\square_H]\mathcal{Y}[\square_{H^\dagger}]H_i (D_\mu H_j)(D_\nu H^{\dagger i})(D^\mu D^\nu H^{\dagger j})$ .
group: (Spin, $SU(3)_c, SU(2)_w, U(1)_y$ )	
$\begin{array}{c} \nearrow \\ \searrow \end{array}$	$\{H_1, H_2\}, \{H^{\dagger 3}, H^{\dagger 4}\}$
*	$(2, 1, 3, 1)$
	$-8\mathcal{O}_1^F - 48\mathcal{O}_2^F - 48\mathcal{O}_3^F$
	$(0, 1, 3, 1)$
	$8\mathcal{O}_1^F$
	$(1, 1, 1, 1)$
	$8\mathcal{O}_1^F + 16\mathcal{O}_3^F$
$\{H_1, H^{\dagger 3}\}, \{H_2, H^{\dagger 4}\}$	
*	$(2, 1, 3, 0)$
	$16\mathcal{O}_1^F - 4\mathcal{O}_2^F + 56\mathcal{O}_3^F$
	$(1, 1, 3, 0)$
	$8\mathcal{O}_1^F - 4\mathcal{O}_2^F + 8\mathcal{O}_3^F$
*	$(0, 1, 3, 0)$
	$8\mathcal{O}_1^F + 4\mathcal{O}_2^F + 16\mathcal{O}_3^F$
*	$(2, 1, 1, 0)$
	$-24\mathcal{O}_1^F - 4\mathcal{O}_2^F - 24\mathcal{O}_3^F$
	$(1, 1, 1, 0)$
	$-4\mathcal{O}_2^F - 8\mathcal{O}_3^F$
	$(0, 1, 1, 0)$
	$4\mathcal{O}_2^F$

Analyticity in complex  $s$  plane (fixed  $t$ )

$$A(s, t) = \frac{1}{2\pi i} \oint_{\mathcal{C}} ds' \frac{A(s', t)}{s' - s}$$

Cauchy's integral formula



Fixed  $t$  dispersion relation

$$A(s, t) \sim \int_{\Lambda^2}^{\infty} \frac{d\mu}{\pi\mu^2} \left[ \frac{s^2}{\mu - s} + \frac{u^2}{\mu - u} \right] \text{Im } A(\mu, t)$$

EFT amplitude

IR ~ UV connection

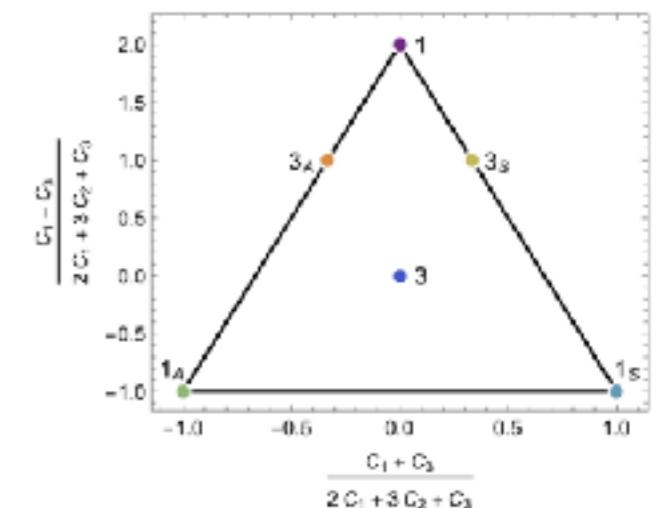
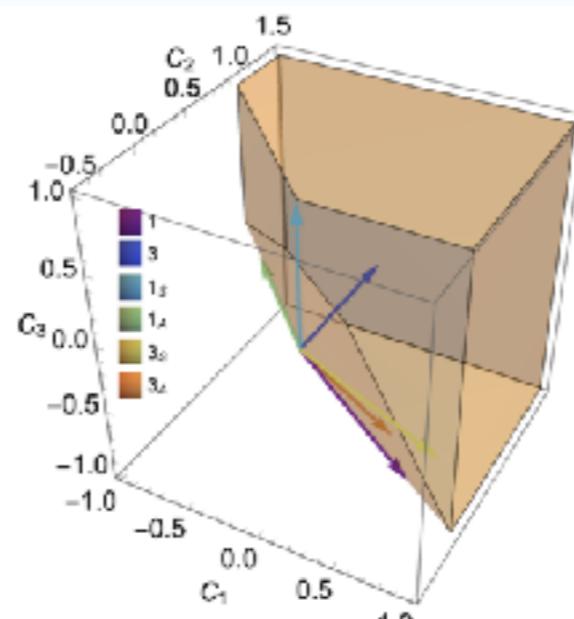
UV full amplitude

$$\text{Disc } A_{ij \rightarrow kl}(s) = A_{ij \rightarrow kl}(s) - A_{kl \rightarrow ij}(s)^* = i \sum_X M_{ij \rightarrow X}(s) M_{kl \rightarrow X}(s)^*$$

In the forward limit, a twice-subtracted dispersion relation

$$\mathcal{M}^{ijkl} = \frac{1}{2\pi} \int_{(c\Lambda)^2}^{\infty} \frac{ds}{s^3} \sum_X [\mathbf{M}_{ij \rightarrow X} \mathbf{M}_{kl \rightarrow X}^* + (j \leftrightarrow l)]$$

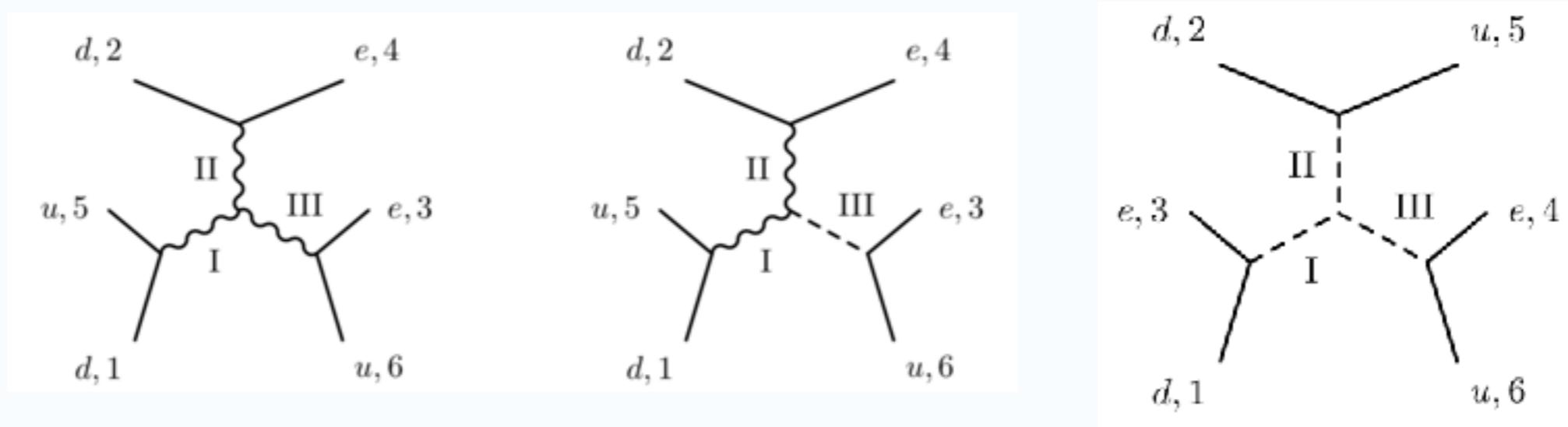
Particle	Spin	Charge/irrep	Interaction	ER	$\vec{e}$	$\vec{e}^{(6)}$
$B_1$	1	$1_1$	$gB_1^{\mu\dagger} (H^T \epsilon \vec{D}_\mu H) + h.c.$	✓	$8(1, 0, -1)$	$2(-1, 2)$
$\Xi_1$	0	$3_1$	$gM\Xi_1^{\mu\dagger} (H^T \epsilon \tau^I H) + h.c.$	✗	$8(0, 1, 0)$	$2(1, 2)$
$S$	0	$1_0(S)$	$gMS (H^\dagger H)$	✓	$2(0, 0, 1)$	$-\frac{1}{2}(1, 0)$
$B$	1	$1_0(A)$	$gB^{\mu} (H^\dagger \vec{D}_\mu H)$	✓	$2(-1, 1, 0)$	$-\frac{1}{2}(1, 4)$
$\Xi_0$	0	$3_0(S)$	$gM\Xi_0^I (H^\dagger \tau^I H)$	✗	$2(2, 0, -1)$	$\frac{1}{2}(1, -4)$
$W$	1	$3_0(A)$	$gW^{\mu I} (H^\dagger \tau^I \vec{D}_\mu H)$	✗	$2(1, 1, -2)$	$-\frac{3}{2}(1, 0)$



[ Cen Zhang, 2021 ]

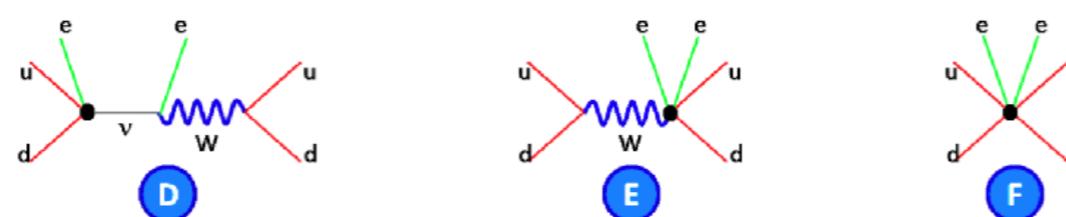
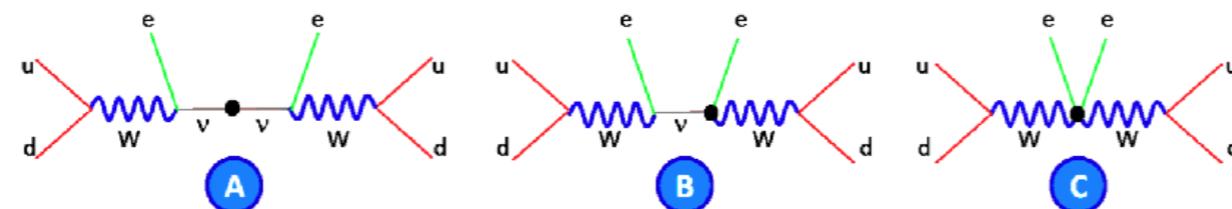
# Dim-9: 0vbb

[ Li, Ni, Xiao, **Yu**, in preparation ]



[ Bonnet, Hirsch, Ota, Winter, 2012]

$$\mathbf{W}^2 \mathcal{B}^J = -s J(J+1) \mathcal{B}^J$$



# **Chiral EFT for EW and QCD**

Bottom-up

Top-down

# EW Chiral Lagrangian

Before the Higgs discovery ...

Weak dynamics @ EW scale

SM, SUSY, etc

**Standard Model EFT**

Strong dynamics @ EW scale

Technicolor, etc

**Electroweak Chiral Lagrangian**



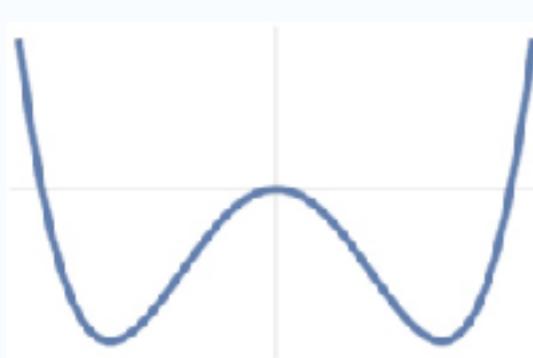
# Higgs EFT

After the Higgs discovery ...

**Next goal: Nature of Higgs boson!**

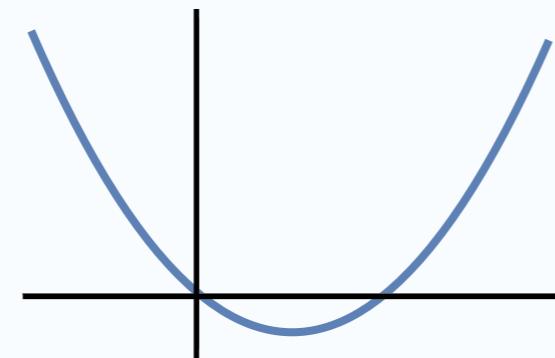
[ Agrawal, Saha, Xu, **Yu**, Yuan, 1907.02078 ]

Landau-Ginzburg Higgs



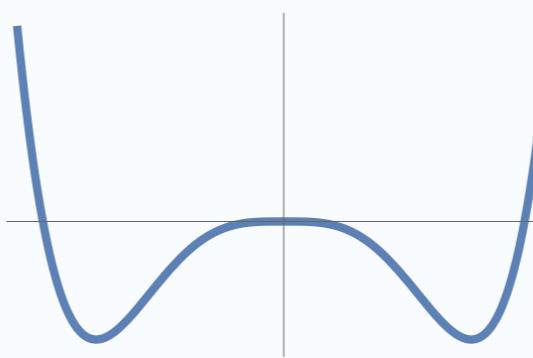
$$V(\phi) = -m^2 \phi^\dagger \phi + \lambda(\phi^\dagger \phi)^2$$

Tadpole-induced Higgs



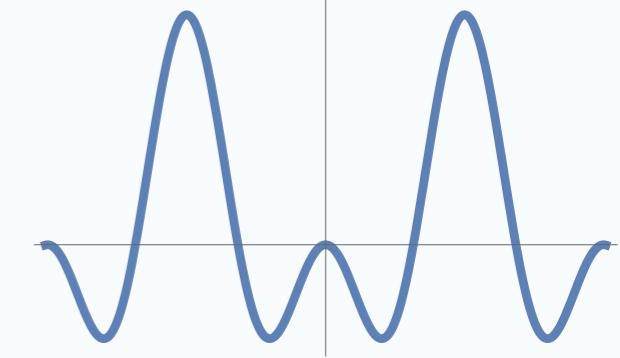
$$V(\phi) = -\mu^3 \sqrt{\phi^\dagger \phi} + m^2 \phi^\dagger \phi$$

Coleman Weinberg Higgs



$$V(\phi) = \lambda(\phi^\dagger \phi)^2 + \epsilon(\phi^\dagger \phi)^2 \log \frac{\phi^\dagger \phi}{\mu^2}$$

Pseudo-Goldstone Higgs



$$V(\phi) = -a \sin^2(\phi/f) + b \sin^4(\phi/f)$$

Fundamental  
particle

Partial Fundamental  
particle

Conformal particle

Composite particle

**Not all of these scenarios can be described in SMEFT**

Also [ Falkowski, Rattazzi 2019 ]

[ Cohen, Craig, Lu, Sutherland, 2021 ]

[ Gomez-Ambrosio, etc, 2022 ]

# Matches Among EFTs

## Standard model EFT

Field d.o.f: all SM fields

Symmetry:  $SU3 \times SU2 \times U1$

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \frac{C_i^{(5)}}{\Lambda_{NP}} Q_i^{(5)} + \frac{C_i^{(6)}}{\Lambda_{NP}^2} Q_i^{(6)} + \dots$$

approximate custodial symmetry  
 $SU(2) \times SU(2)$

$$\Sigma \equiv (\Phi^c, \Phi) = \begin{pmatrix} \Phi^0* & \Phi^+ \\ -\Phi^- & \Phi^0 \end{pmatrix} \rightarrow g_L \Sigma g_R^\dagger$$

$$(g_L, g_R) \in \mathbf{SU(2)} \times \mathbf{SU(2)}$$

$$\langle \Sigma \rangle = \begin{pmatrix} v & 0 \\ 0 & v \end{pmatrix} \neq 0$$

The vacuum is not invariant (SSB)

## EW Chiral Lagrangian

## Low energy EFT

SM fields except Higgs, top, W, Z

Symmetry:  $SU3 \times U1$

$$\mathcal{L}_{LEFT} = \mathcal{L}_{QED+QCD} + \frac{C_i^{(5)}}{M_W} O_i^{(5)} + \frac{C_i^{(6)}}{M_W^2} O_i^{(6)} + \dots$$

approximate chiral symmetry  
 $SU(2) \times SU(2)$

$$\mathbf{q}_L \rightarrow g_L \mathbf{q}_L, \quad \mathbf{q}_R \rightarrow g_R \mathbf{q}_R,$$

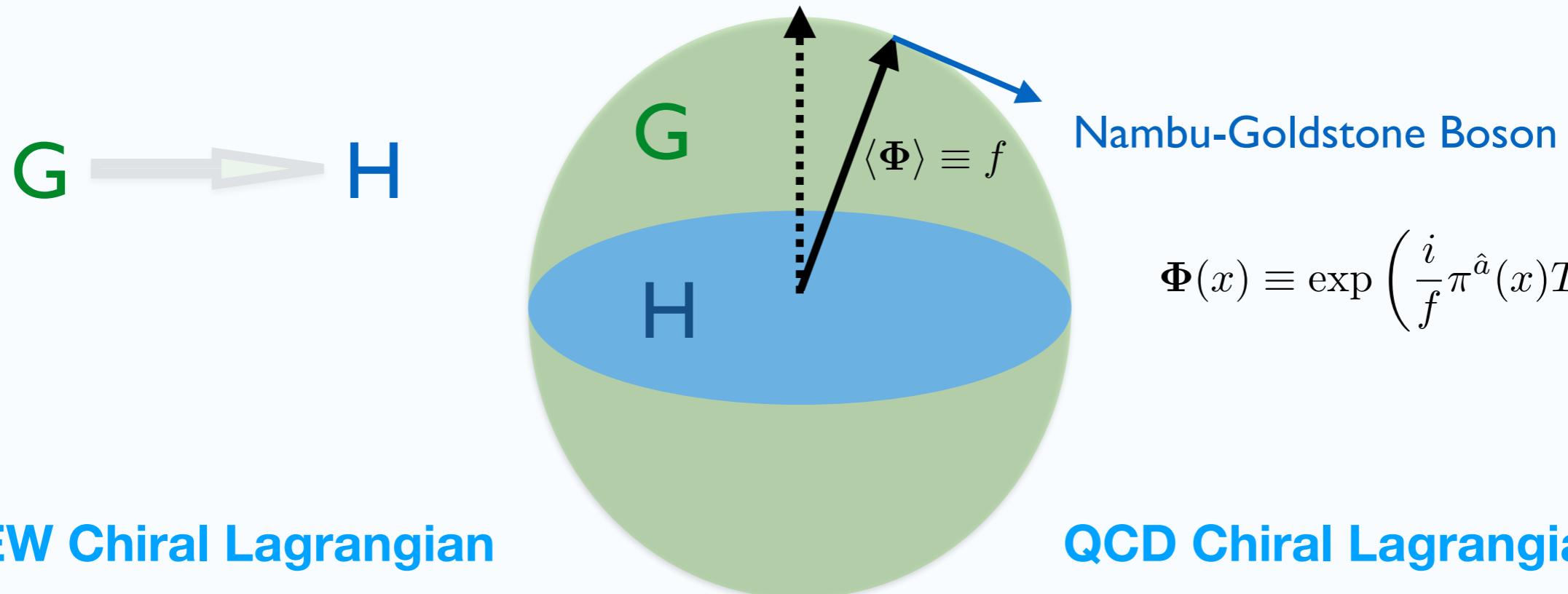
$$(g_L, g_R) \in \mathbf{SU(2)} \times \mathbf{SU(2)}$$

$$\langle 0 | (\bar{\mathbf{q}}_L \mathbf{q}_R + \bar{\mathbf{q}}_R \mathbf{q}_L) | 0 \rangle \neq 0$$

## QCD Chiral Lagrangian

# EFTs in Broken Phase

Chiral Lagrangian description on the SSB



**EW Chiral Lagrangian**

$$\Phi \equiv \frac{1}{\sqrt{2}} \vec{\sigma} \cdot \vec{\varphi} = \begin{pmatrix} \frac{1}{\sqrt{2}}\varphi^0 & \varphi^+ \\ \varphi^- & -\frac{1}{\sqrt{2}}\varphi^0 \end{pmatrix}$$

SM fields and Goldstone

$$G = SU(2)_L \times SU(2)_R \times U(1)_{B-L} \quad H = SU(2)_{L+R} \times U(1)_{B-L}$$

$$SU(2)_L \times U(1)_Y \qquad \qquad \qquad U(1)_{\text{em}}$$

**QCD Chiral Lagrangian**

$$\Phi = \frac{\vec{\lambda}}{\sqrt{2}} \vec{\phi} = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\sqrt{\frac{2}{3}}\eta \end{pmatrix}$$

meson and baryon

$$G = SU(3)_L \times SU(3)_R \qquad H = SU(3)_V$$

$$SU(3) \times U(1)_{\text{em}} \qquad \qquad \qquad U(1)_{\text{em}}$$

# CCWZ for Goldstone Boson

Define the Goldstone matrix, which transform nonlinearly under G

$$\Omega(\Pi) \equiv \exp \left[ \frac{i}{2f} \Pi(x) \right] \rightarrow \Omega(\Pi^{(g)}) = g\Omega(\Pi)\hbar^{-1}(\Pi; g)$$

## CCWZ Coset

[Callan, Coleman, Wess, Zumino, 1969]

$$-i\Omega^\dagger \partial_\mu \Omega = d_\mu^{\hat{a}} T^{\hat{a}} + E_\mu^a T^a \equiv d_\mu + E_\mu$$

$$d_\mu \rightarrow \hbar d_\mu \hbar^{-1}, \quad E_\mu \rightarrow \hbar E_\mu \hbar^{-1} - i\hbar \partial_\mu \hbar^{-1}$$

$$\partial_\mu \rightarrow D_\mu = \partial_\mu + iA_\mu \quad A_{\mu\underline{a}} = A_{\mu}^{\hat{a}} T^{\hat{a}} + A_{\mu}^a T^a$$

Building block

$$d_\mu(\Pi), \quad E_{\mu\nu}(\Pi) \quad \nabla_\mu \equiv \partial_\mu + iE_\mu$$

$$f_{\mu\nu} = \Omega^\dagger F_{\mu\nu} \Omega = f_{\mu\nu}^{-\hat{a}} T^{\hat{a}} + f_{\mu\nu}^{+a} T^a$$

$$[T_{\hat{a}}, T_{\hat{b}}] \propto T_c$$

## Symmetric Coset

$$\Omega \rightarrow g\Omega\hbar^{-1}, \quad \Omega \rightarrow \hbar\Omega g_R^{-1}$$

$$U \equiv \Omega^2 \rightarrow g U g_R^{-1}$$

$$A_\mu^{(R)} \equiv A_\mu^a T^a - A_\mu^{\hat{a}} T^{\hat{a}} \quad D_\mu U \equiv \partial_\mu U + iA_\mu U - iUA_\mu^{(R)}$$

Building block

$$E_{\mu\nu} = -i[u_\mu, u_\nu] + f_{\mu\nu}^+$$

$$d_\mu = u_\mu$$

$$u_\mu = i\Omega(D_\mu U)^\dagger \Omega \quad D_\mu$$

$$f_{\mu\nu}^\pm = \frac{1}{2} (f_{\mu\nu} \pm f_{\mu\nu}^{(R)}) = \Omega^\dagger F_{\mu\nu} \Omega \pm F_{\mu\nu}^{(R)}$$

# Chiral Lag for QCD and EW

$$\Omega(\Pi) \equiv \begin{bmatrix} u(\Pi) & 0 \\ 0 & u^\dagger(\Pi) \end{bmatrix} \quad u \rightarrow \sqrt{\mathfrak{g}_L U \mathfrak{g}_R^\dagger} = \mathfrak{g}_L u \mathfrak{h}^{-1} = \mathfrak{h}^{-1} u \mathfrak{g}_R$$

$$U(\Pi) \equiv u^2(\Pi) \longrightarrow \mathfrak{g}_L \mathbf{U}(\Pi) \mathfrak{g}_R^\dagger$$

**QCD Chiral Lag**

$$u_\mu \rightarrow \mathfrak{h} u_\mu \mathfrak{h}^{-1}$$

$$u_\mu = i \left[ u^\dagger (\partial_\mu - ir_\mu) u - u (\partial_\mu - il_\mu) u^\dagger \right]$$

**EW Chiral Lag**

$$\mathbf{V}_\mu \rightarrow \mathfrak{g}_L \mathbf{V} \mathfrak{g}_L^{-1}$$

$$\mathbf{V}_\mu(x) = i \mathbf{U}(x) D_\mu \mathbf{U}(x)^\dagger$$

$$\chi_{\pm} = u^\dagger \chi u^\dagger \pm u \chi^\dagger u,$$

$$f_{\mu\nu}^{\pm} = u f_{\mu\nu}^L u^\dagger \pm u^\dagger f_{\mu\nu}^R u,$$

$$\hat{W}_{\mu\nu} \longrightarrow \mathfrak{g}_L \hat{W}_{\mu\nu} \mathfrak{g}_L^\dagger$$

$$\hat{B}_{\mu\nu} \longrightarrow \mathfrak{g}_R \hat{B}_{\mu\nu} \mathfrak{g}_R^\dagger$$

$$B \rightarrow \mathfrak{h} B \mathfrak{h}^{-1}$$

$$\psi_L \longrightarrow \mathfrak{g}_L \psi_L$$

$$D_\mu A = \partial_\mu A + [\Gamma_\mu, A]$$

$$\mathbf{U} \psi_R \longrightarrow \mathfrak{g}_L \mathbf{U} \psi_R$$

$$[D_\mu, D_\nu] A = \frac{1}{4} [[u_\mu, u_\nu], A] - \frac{i}{2} [f_{\mu\nu}^\perp, A]$$

$$\mathbf{T} = \mathbf{U} \mathcal{T}_R \mathbf{U}^\dagger \longrightarrow \mathfrak{g}_L \mathbf{T} \mathfrak{g}_L^\dagger$$

$$\Gamma_\mu = \frac{1}{2} \left[ u^\dagger (\partial_\mu - ir_\mu) u + u (\partial_\mu - il_\mu) u^\dagger \right]$$

$$\mathbf{Y} = \mathbf{U} \mathcal{Y}_R \mathbf{U}^\dagger \longrightarrow \mathfrak{g}_L \mathbf{Y} \mathfrak{g}_L^\dagger$$

$$\Gamma^{\mu\nu} = \nabla^\mu \Gamma^\nu - \nabla^\nu \Gamma^\mu - [\Gamma^\mu, \Gamma^\nu] = \frac{1}{4} [u^\mu, u^\nu] - \frac{i}{2} f_+^{\mu\nu}$$

[ See also Shao-Zhou Jiang's talk ]

# Higgs EFT

EW chiral Lagrangian

EWChL with light Higgs

Higgs EFT

LO and NLO boson 2012

NLO fermion sector

2020

Full NLO and NNLO

LO Lagrangian

[ Weinberg, 1979 ]

NLO Bosonic Lagrangian

[ Appelquist, Bernard, 1980 ]

[ Longhitano, 1980, 1981 ]

[ Feruglio, 1993 ]

[ Herrero, Morales, 1993 ]

NLO Fermionic Lagrangian

[ Buchalla, Cata, 2013 ]

[ Buchalla, Cata, Krause, 2014 ]

[ Brivio, Gonzalez-Fraile/Garcia, Merlo, 2016 ]

[ Pich, Rosell, Santos, Sanz-Cillero, 2015, 2018 ]

Complete NLO Lagrangian

237 (8595) operators for one (three)

[ Sun, Xiao, Yu, 2206.07722 ]

$$\begin{aligned}
 \mathcal{O}_{\mu\nu}^{(1)\text{h}\nu} &= (\bar{q}_{L,\mu} \gamma_\nu \tau^I \overline{U}_{R,\nu}) \bar{q}_{L,\nu} \gamma^\mu U^I \tau^I \overline{U}_{R,\mu} F_{\mu\nu}^{(1)\text{h}\nu}(k), \\
 \mathcal{O}_{\mu\nu}^{(1)\text{b}\nu} &= (\bar{q}_{L,\mu} \gamma_\nu \lambda^A \tau^I \overline{U}_{R,\nu}) \bar{q}_{L,\nu} \gamma^\mu \lambda^A U^I \tau^I \overline{U}_{R,\mu} F_{\mu\nu}^{(1)\text{b}\nu}(k), \\
 \mathcal{O}_{\mu\nu}^{(1)\text{f}\nu} &= (\bar{q}_{L,\mu} \gamma_\nu \tau^I \overline{U}_{R,\nu}) (\bar{q}_{L,\nu} \gamma^\mu \tau^I U^I \overline{U}_{R,\mu}) F_{\mu\nu}^{(1)\text{f}\nu}(k), \\
 \mathcal{O}_{\mu\nu}^{(1)\text{bf}} &= (\bar{q}_{L,\mu} \gamma_\nu \tau^I \overline{U}_{R,\nu}) (\bar{q}_{L,\nu} \gamma^\mu \tau^I U^I \overline{U}_{R,\mu}) F_{\mu\nu}^{(1)\text{bf}}(k), \\
 \mathcal{O}_{\mu\nu}^{(1)\text{ff}} &= (\bar{q}_{L,\mu} \gamma_\nu \tau^I \overline{U}_{R,\nu}) (\bar{q}_{L,\nu} \gamma^\mu \tau^I U^I \overline{U}_{R,\mu}) F_{\mu\nu}^{(1)\text{ff}}(k), \\
 \mathcal{O}_{\mu\nu}^{(1)\text{bf}} &= (\bar{q}_{L,\mu} \gamma_\nu \tau^I \overline{U}_{R,\nu}) (\bar{q}_{L,\nu} \gamma^\mu \tau^I U^I \overline{U}_{R,\mu}) F_{\mu\nu}^{(1)\text{bf}}(k), \\
 \mathcal{O}_{\mu\nu}^{(1)\text{ff}} &= (\bar{q}_{L,\mu} \gamma_\nu \tau^I \overline{U}_{R,\nu}) (\bar{q}_{L,\nu} \gamma^\mu \tau^I U^I \overline{U}_{R,\mu}) F_{\mu\nu}^{(1)\text{ff}}(k), \\
 \mathcal{O}_{\mu\nu}^{(1)\text{bf}} &= \mathcal{Y} \left[ \frac{\partial}{\partial k_\mu} e^{ik_\nu x^\mu} e^{ik_\nu x^\mu} ((T U)^T)_{\mu\nu} C (T \overline{U})_{\mu\nu} \right] \bar{q}_{L,\mu} C_{R,\nu} F_{\mu\nu}^{(1)\text{bf}}(k), \\
 \mathcal{O}_{\mu\nu}^{(1)\text{ff}} &= \mathcal{Y} \left[ \frac{\partial}{\partial k_\mu} e^{ik_\nu x^\mu} e^{ik_\nu x^\mu} ((T U)^T)_{\mu\nu} C (T \overline{U})_{\mu\nu} \right] \bar{q}_{L,\mu} C_{R,\nu} F_{\mu\nu}^{(1)\text{ff}}(k).
 \end{aligned}$$

Complete NNLO Lagrangian

11506(1927574) NNLO operators with flavor number 1(3).

[ Sun, Xiao, Yu, in preparation ]

# Adler Zero Condition

The amplitude in the soft limit of an external leg s

$$\mathcal{A}(1, \dots, N, s) \xrightarrow{p_s \rightarrow 0} \begin{cases} (S^{(0)}(s) + S^{(\text{sub})}(s)) \mathcal{A}(1, \dots, N) \\ \mathcal{O}(p_s^\sigma) \quad \text{for Goldstone Boson} \end{cases}$$

[ Adler, 1965 ]

[ Low, 2014 ]

[ Cheung, et.al, 2014, 2015 ]

$\{-1/2, -1/2, 1, 0, 0\}$

1	1	1	4
2	2	2	5
4	5		

1	1	1	2
2	2	5	5
4	4		

1	1	1	2
2	2	4	4
5	5		

1	1	1	2
2	2	4	5
4	5		

Expand the soft-limit amplitude into the SSYT basis

$$\mathcal{B}_i^{(N)}(p_\pi \rightarrow 0) = \sum_{l=1}^{d_N} \mathcal{K}_{il} \mathcal{B}_l^{(N)}$$

Put constraints on the SSYT basis

1	1	1	4
2	2	2	5
4	5		

1	1	1	2
2	2	4	5
4	5		

[ Sun, Xiao, Yu, 2206.07722 ]

[ Low, Shu, Xiao, Zheng, 2022 ]

# Spurion Technique

The  $SU(2)$  spurion is introduced to parametrize the custodial symmetry breaking

$$t_i \in \mathbf{2} \sim \square$$

$$\epsilon_{ij} t^j \in \bar{\mathbf{2}} \sim \square$$

$$t^I \tau_i^{Ik} \epsilon_{kj} \in \mathbf{3} \sim \square\square$$

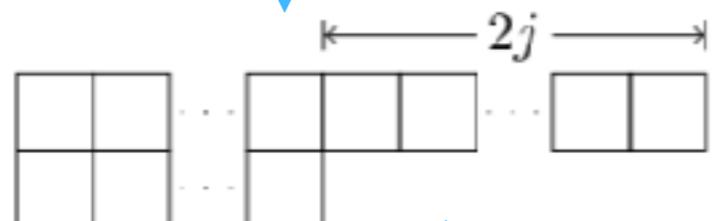
$$\mathbf{T}^I \tau^{Ik}{}_i \epsilon_{kj} \in [i | j],$$

$$\mathbf{T}^{\{I_1} \dots \mathbf{T}^{I_j\}} \in \text{spin } j$$

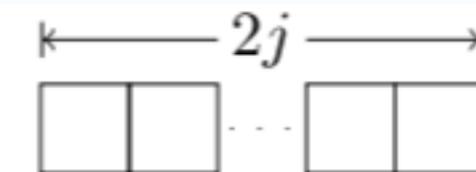
$$\begin{aligned} \mathbf{T}^I \mathbf{T}^J &= \mathbf{T}^2 \delta^{IJ} + \mathbf{T}^{[I} \mathbf{T}^{J]} + \mathbf{T}^{(I} \mathbf{T}^{J)}, \\ \mathbf{3} \otimes \mathbf{3} &= \mathbf{1} + \mathbf{3} + \mathbf{5}. \end{aligned}$$

$$\epsilon^{IJK} \mathbf{T}^I \mathbf{T}^J A^K$$

**Littlewood-Richarson rules**



**Symmetric highest weight**



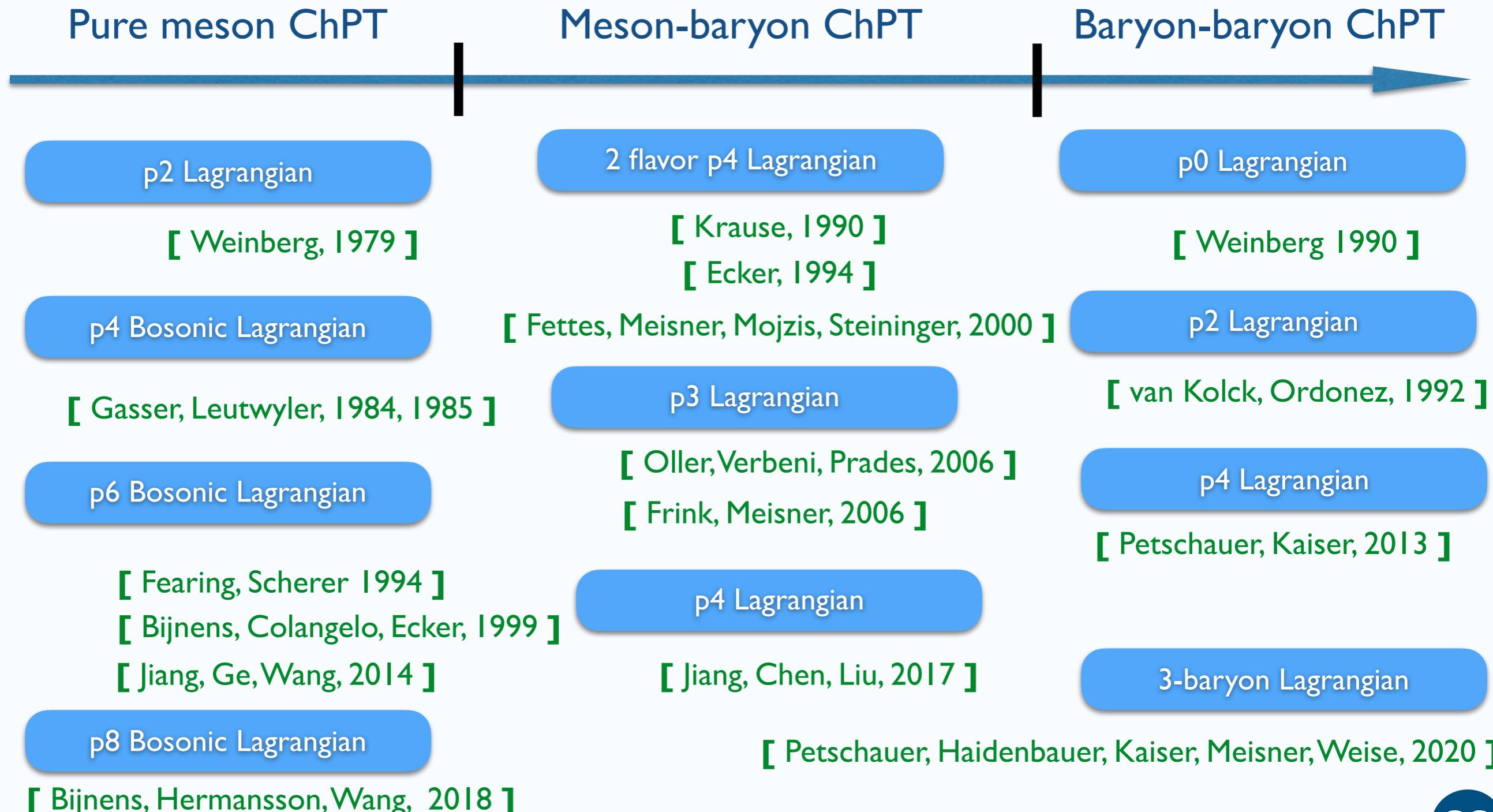
**Gauge Singlet**

$$SU(2) \sim \square\square \dots \square$$

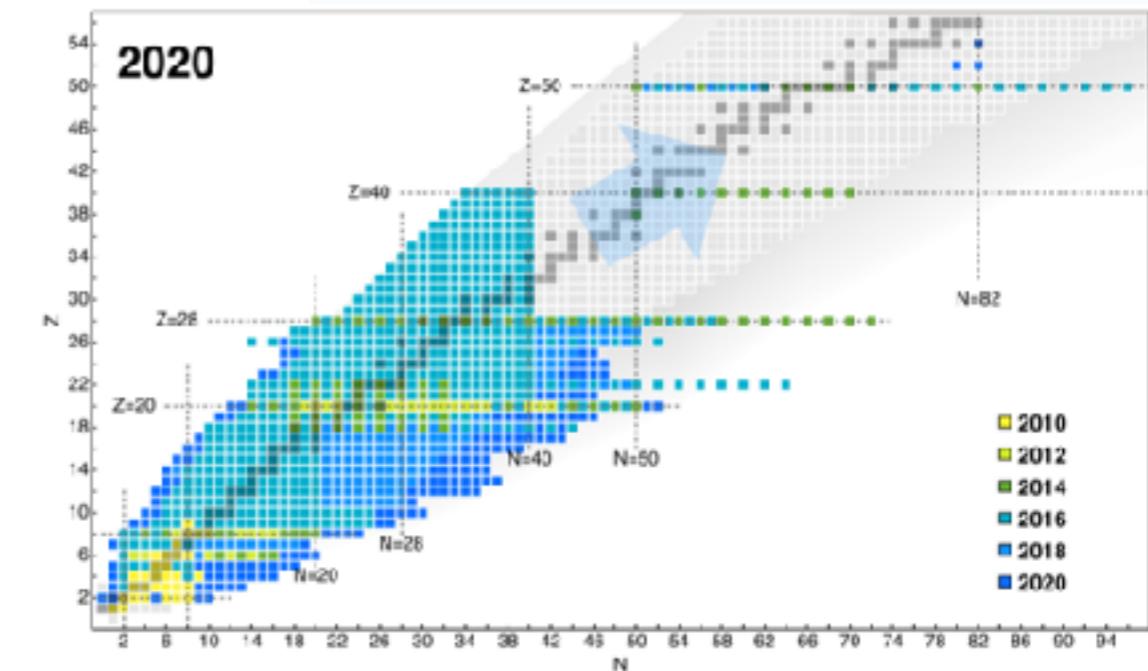
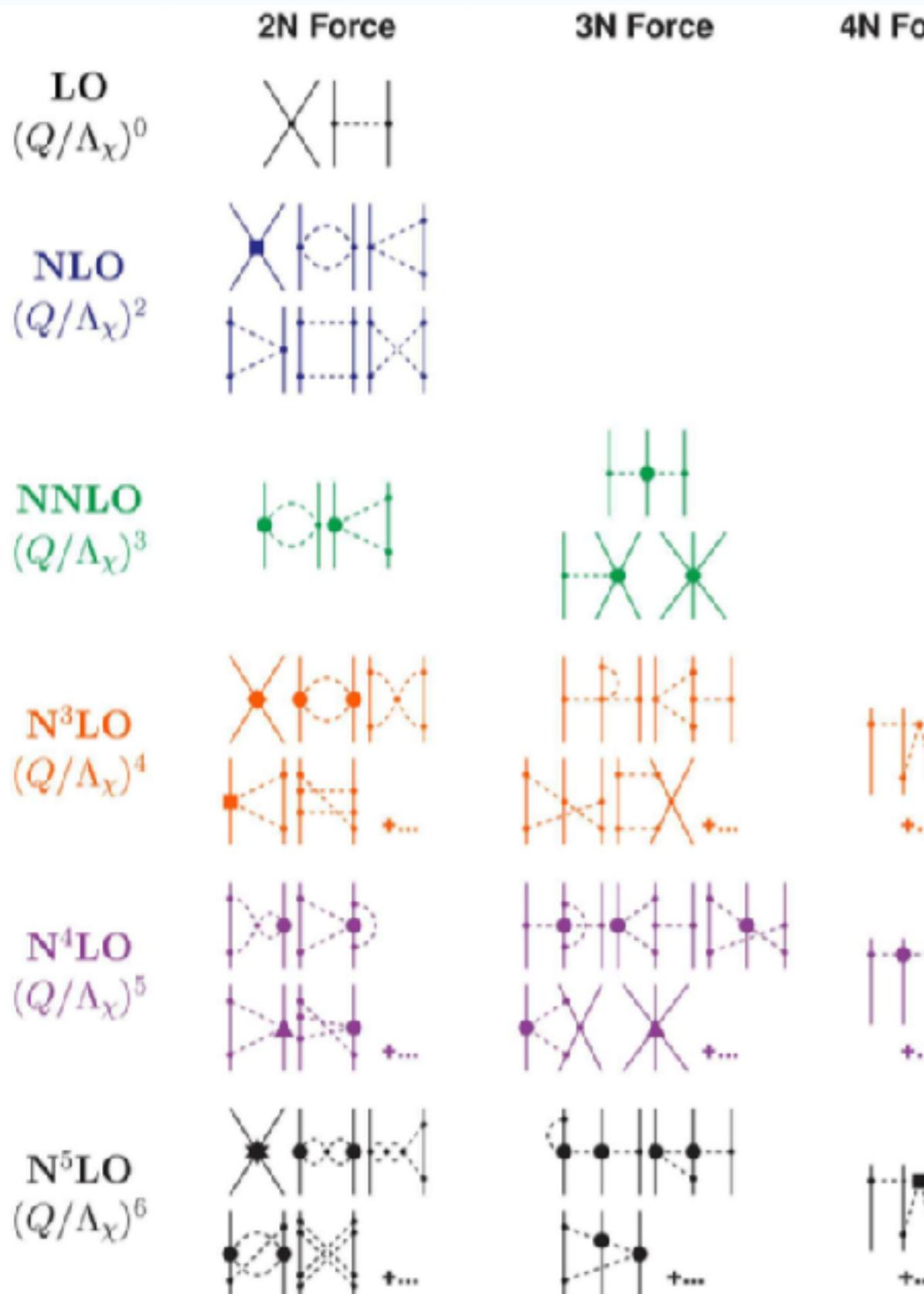
[ Sun, Xiao, Yu, 2206.07722 ]

# QCD Chiral Lagrangian

Long and old history since 1979 Weinberg and 1990 Weinberg



# Chiral EFT Up to N5LO



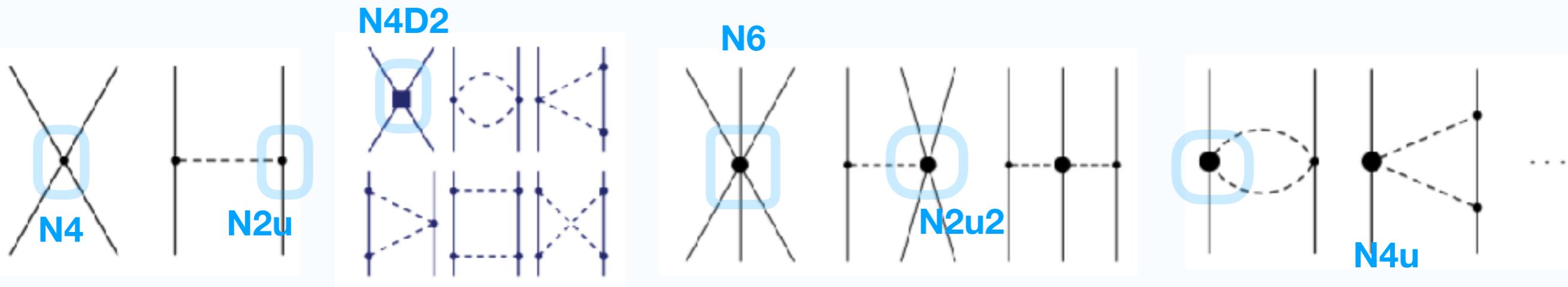
[ See also Jiang-Ming Yao's talk ]

[ Entem, Machleidt, Nosyk, 2020 ]

Also [ Hebeler, 2020 ]

# Baryon-Baryon and Three-Baryon

Extend to the SU(3) flavor for hyperon-nucleon interactions



[ Petschauer, Kaiser, 2013 ]

N6

N2u2

N4u

$$\langle \bar{B}B\bar{B}B \rangle, \langle \bar{B}\bar{B}BB \rangle, \langle \bar{B}B \rangle \langle \bar{B}B \rangle, \langle \bar{B}\bar{B} \rangle \langle BB \rangle, \\ \langle \bar{B}\chi B\bar{B}B \rangle, \langle \bar{B}B\chi\bar{B}B \rangle, \langle \bar{B}\chi B \rangle \langle \bar{B}B \rangle, \dots$$

[ Petschauer, Haidenbauer, Kaiser, Meisner, Weise, 2020 ]

$$\langle \bar{B}\bar{B}\bar{B}BBB \rangle, \langle \bar{B}\bar{B}B\bar{B}BB \rangle, \langle \bar{B}\bar{B}BBB\bar{B}B \rangle, \\ \langle \bar{B}B\bar{B}B\bar{B}B \rangle, \langle \bar{B}\bar{B}BB \rangle \langle \bar{B}B \rangle, \langle \bar{B}B\bar{B}B \rangle \langle \bar{B}B \rangle, \\ \langle \bar{B}\bar{B}\bar{B}B \rangle \langle BB \rangle, \langle \bar{B}\bar{B}\bar{B} \rangle \langle BBB \rangle, \langle \bar{B}\bar{B}\bar{B} \rangle \langle B\bar{B}B \rangle, \\ \langle \bar{B}B \rangle \langle \bar{B}B \rangle \langle \bar{B}B \rangle, \langle \bar{B}\bar{B} \rangle \langle \bar{B}B \rangle \langle BB \rangle,$$

The Young tensor technique can also applied to ChPT

Complete and independent relativistic operators, then heavy baryon expansion

IBP, EOM (not external source), Bianchi, Fierz-Schouten,  
No need Cayley-Hamilton relation

[ Sun, Wang, Yu, in préparation ]

# Summary

1. paradigm shift in new physics searches

**Bottom-up EFT provides a clear pathway to new physics step by step**

2. New way of constructing EFT operators

**SMEFT, LEFT, gravity EFT, Higgs EFT, QCD chiral Lag, nuclear EFT, etc**

Usual Construction

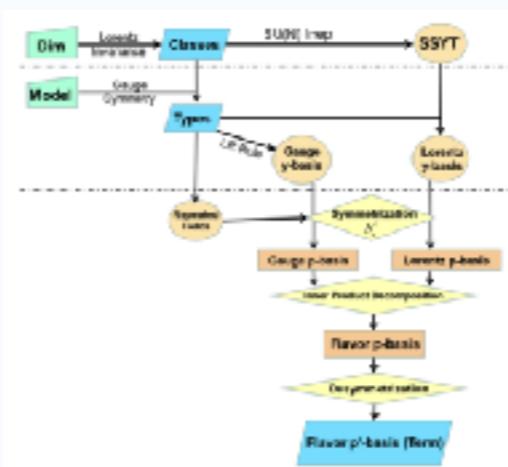
Young Tensor Technique

Complete UVs

$X^3$	$\varphi^k \text{ and } \varphi^l D^3$	$\varphi^2 \varphi^3$
$Q_G$	$f^{ABC} G_A^{\mu\nu} G_B^{\rho\sigma} G_C^{\lambda\eta}$	$Q_\psi$ $(\varphi^\mu \varphi)^\lambda$
$Q_{G\bar{G}}$	$f^{AB\bar{C}} \bar{G}_A^{\mu\nu} G_B^{\rho\sigma} G_{\bar{C}}^{\lambda\eta}$	$Q_{\varphi\bar{\varphi}}$ $(\varphi^\mu \varphi) \square (\varphi^\rho \varphi)$
$Q_{W\bar{W}}$	$e^{i\partial^\mu W_\mu^A} W_\nu^B W_\nu^C$	$Q_{\varphi W}$ $(\varphi^\mu D_\nu \varphi)^B (\varphi^\nu D_\mu \varphi)^C$
$Q_{W\bar{B}}$	$e^{i\partial^\mu W_\mu^A} W_\nu^B \bar{B}_\nu^C$	$Q_{\varphi\bar{B}}$ $(\varphi^\mu D_\nu \varphi)^B (\bar{B}_\mu \varphi)^C$

$(L,L)(R,R)$	$(R,R)(L,R)$	$(L,L)(R,R)$	
$Q_0$	$(\bar{q}_1 q_1)(\bar{q}_2 q_2)$	$Q_{\bar{q}q}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$
$Q_{\bar{q}q}^{(1)}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$	$Q_{\bar{q}q}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$
$Q_{\bar{q}q}^{(2)}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$	$Q_{\bar{q}q}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$
$Q_{\bar{q}q}^{(3)}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$	$Q_{\bar{q}q}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$
$Q_{\bar{q}q}^{(4)}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$	$Q_{\bar{q}q}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$
$(LR)(RL) \text{ and } (LR)(LR)$	$S\text{-violating}$		
$Q_{\bar{q}q\gamma}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$	$Q_{\bar{q}q\gamma}$	$e^{i\partial^\mu} \epsilon_{\mu\nu} [(\bar{q}_1^\mu)^2 C \bar{q}_2^\nu] [(\bar{q}_2^\mu)^2 O_1]$
$Q_{\bar{q}q\gamma\gamma}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$	$Q_{\bar{q}q\gamma\gamma}$	$e^{i\partial^\mu} \epsilon_{\mu\nu} [(\bar{q}_1^\mu)^2 C \bar{q}_2^\nu] [(\bar{q}_2^\mu)^2 C_1]$
$Q_{\bar{q}q\gamma\gamma\gamma}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$	$Q_{\bar{q}q\gamma\gamma\gamma}$	$e^{i\partial^\mu} \epsilon_{\mu\nu} \epsilon_{\nu\rho} [(\bar{q}_1^\mu)^2 C \bar{q}_2^\nu] [(\bar{q}_2^\mu)^2 C_1]$
$Q_{\bar{q}q\gamma\gamma\gamma\gamma}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$	$Q_{\bar{q}q\gamma\gamma\gamma\gamma}$	$e^{i\partial^\mu} [(\bar{q}_1^\mu)^2 C_1] [(\bar{q}_2^\mu)^2 C_1]$
$Q_{\bar{q}q\gamma\gamma\gamma\gamma\gamma}$	$(\bar{q}_1 \gamma_\mu q_1)(\bar{q}_2 \gamma^\mu q_2)$		

Any operator  
to any mass dimension



Partial wave for  
UV resonances

Partial wave	Resonance	Mass
(1/2, 1/2)	$J/\psi$	3100 MeV
(1/2, 1/2)	$\psi'$	3680 MeV
(1/2, 1/2)	$\chi_1^0$	3770 MeV
(1/2, 1/2)	$\chi_2^0$	3900 MeV
(1/2, 1/2)	$\chi_3^0$	4100 MeV
(1/2, 1/2)	$\chi_4^0$	4200 MeV
(1/2, 1/2)	$\chi_5^0$	4300 MeV
(1/2, 1/2)	$\chi_6^0$	4400 MeV
(1/2, 1/2)	$\chi_7^0$	4500 MeV
(1/2, 1/2)	$\chi_8^0$	4600 MeV
(1/2, 1/2)	$\chi_9^0$	4700 MeV
(1/2, 1/2)	$\chi_1^1$	4800 MeV
(1/2, 1/2)	$\chi_2^1$	4900 MeV
(1/2, 1/2)	$\chi_3^1$	5000 MeV
(1/2, 1/2)	$\chi_4^1$	5100 MeV
(1/2, 1/2)	$\chi_5^1$	5200 MeV
(1/2, 1/2)	$\chi_6^1$	5300 MeV
(1/2, 1/2)	$\chi_7^1$	5400 MeV
(1/2, 1/2)	$\chi_8^1$	5500 MeV
(1/2, 1/2)	$\chi_9^1$	5600 MeV
(1/2, 1/2)	$\chi_1^2$	5700 MeV
(1/2, 1/2)	$\chi_2^2$	5800 MeV
(1/2, 1/2)	$\chi_3^2$	5900 MeV
(1/2, 1/2)	$\chi_4^2$	6000 MeV
(1/2, 1/2)	$\chi_5^2$	6100 MeV
(1/2, 1/2)	$\chi_6^2$	6200 MeV
(1/2, 1/2)	$\chi_7^2$	6300 MeV
(1/2, 1/2)	$\chi_8^2$	6400 MeV
(1/2, 1/2)	$\chi_9^2$	6500 MeV
(1/2, 1/2)	$\chi_1^3$	6600 MeV
(1/2, 1/2)	$\chi_2^3$	6700 MeV
(1/2, 1/2)	$\chi_3^3$	6800 MeV
(1/2, 1/2)	$\chi_4^3$	6900 MeV
(1/2, 1/2)	$\chi_5^3$	7000 MeV
(1/2, 1/2)	$\chi_6^3$	7100 MeV
(1/2, 1/2)	$\chi_7^3$	7200 MeV
(1/2, 1/2)	$\chi_8^3$	7300 MeV
(1/2, 1/2)	$\chi_9^3$	7400 MeV
(1/2, 1/2)	$\chi_1^4$	7500 MeV
(1/2, 1/2)	$\chi_2^4$	7600 MeV
(1/2, 1/2)	$\chi_3^4$	7700 MeV
(1/2, 1/2)	$\chi_4^4$	7800 MeV
(1/2, 1/2)	$\chi_5^4$	7900 MeV
(1/2, 1/2)	$\chi_6^4$	8000 MeV
(1/2, 1/2)	$\chi_7^4$	8100 MeV
(1/2, 1/2)	$\chi_8^4$	8200 MeV
(1/2, 1/2)	$\chi_9^4$	8300 MeV
(1/2, 1/2)	$\chi_1^5$	8400 MeV
(1/2, 1/2)	$\chi_2^5$	8500 MeV
(1/2, 1/2)	$\chi_3^5$	8600 MeV
(1/2, 1/2)	$\chi_4^5$	8700 MeV
(1/2, 1/2)	$\chi_5^5$	8800 MeV
(1/2, 1/2)	$\chi_6^5$	8900 MeV
(1/2, 1/2)	$\chi_7^5$	9000 MeV
(1/2, 1/2)	$\chi_8^5$	9100 MeV
(1/2, 1/2)	$\chi_9^5$	9200 MeV
(1/2, 1/2)	$\chi_1^6$	9300 MeV
(1/2, 1/2)	$\chi_2^6$	9400 MeV
(1/2, 1/2)	$\chi_3^6$	9500 MeV
(1/2, 1/2)	$\chi_4^6$	9600 MeV
(1/2, 1/2)	$\chi_5^6$	9700 MeV
(1/2, 1/2)	$\chi_6^6$	9800 MeV
(1/2, 1/2)	$\chi_7^6$	9900 MeV
(1/2, 1/2)	$\chi_8^6$	10000 MeV
(1/2, 1/2)	$\chi_9^6$	10100 MeV
(1/2, 1/2)	$\chi_1^7$	10200 MeV
(1/2, 1/2)	$\chi_2^7$	10300 MeV
(1/2, 1/2)	$\chi_3^7$	10400 MeV
(1/2, 1/2)	$\chi_4^7$	10500 MeV
(1/2, 1/2)	$\chi_5^7$	10600 MeV
(1/2, 1/2)	$\chi_6^7$	10700 MeV
(1/2, 1/2)	$\chi_7^7$	10800 MeV
(1/2, 1/2)	$\chi_8^7$	10900 MeV
(1/2, 1/2)	$\chi_9^7$	11000 MeV
(1/2, 1/2)	$\chi_1^8$	11100 MeV
(1/2, 1/2)	$\chi_2^8$	11200 MeV
(1/2, 1/2)	$\chi_3^8$	11300 MeV
(1/2, 1/2)	$\chi_4^8$	11400 MeV
(1/2, 1/2)	$\chi_5^8$	11500 MeV
(1/2, 1/2)	$\chi_6^8$	11600 MeV
(1/2, 1/2)	$\chi_7^8$	11700 MeV
(1/2, 1/2)	$\chi_8^8$	11800 MeV
(1/2, 1/2)	$\chi_9^8$	11900 MeV
(1/2, 1/2)	$\chi_1^9$	12000 MeV
(1/2, 1/2)	$\chi_2^9$	12100 MeV
(1/2, 1/2)	$\chi_3^9$	12200 MeV
(1/2, 1/2)	$\chi_4^9$	12300 MeV
(1/2, 1/2)	$\chi_5^9$	12400 MeV
(1/2, 1/2)	$\chi_6^9$	12500 MeV
(1/2, 1/2)	$\chi_7^9$	12600 MeV
(1/2, 1/2)	$\chi_8^9$	12700 MeV
(1/2, 1/2)	$\chi_9^9$	12800 MeV
(1/2, 1/2)	$\chi_1^{10}$	12900 MeV
(1/2, 1/2)	$\chi_2^{10}$	13000 MeV
(1/2, 1/2)	$\chi_3^{10}$	13100 MeV
(1/2, 1/2)	$\chi_4^{10}$	13200 MeV
(1/2, 1/2)	$\chi_5^{10}$	13300 MeV
(1/2, 1/2)	$\chi_6^{10}$	13400 MeV
(1/2, 1/2)	$\chi_7^{10}$	13500 MeV
(1/2, 1/2)	$\chi_8^{10}$	13600 MeV
(1/2, 1/2)	$\chi_9^{10}$	13700 MeV
(1/2, 1/2)	$\chi_1^{11}$	13800 MeV
(1/2, 1/2)	$\chi_2^{11}$	13900 MeV
(1/2, 1/2)	$\chi_3^{11}$	14000 MeV
(1/2, 1/2)	$\chi_4^{11}$	14100 MeV
(1/2, 1/2)	$\chi_5^{11}$	14200 MeV
(1/2, 1/2)	$\chi_6^{11}$	14300 MeV
(1/2, 1/2)	$\chi_7^{11}$	14400 MeV
(1/2, 1/2)	$\chi_8^{11}$	14500 MeV
(1/2, 1/2)	$\chi_9^{11}$	14600 MeV
(1/2, 1/2)	$\chi_1^{12}$	14700 MeV
(1/2, 1/2)	$\chi_2^{12}$	14800 MeV
(1/2, 1/2)	$\chi_3^{12}$	14900 MeV
(1/2, 1/2)	$\chi_4^{12}$	15000 MeV
(1/2, 1/2)	$\chi_5^{12}$	15100 MeV
(1/2, 1/2)	$\chi_6^{12}$	15200 MeV
(1/2, 1/2)	$\chi_7^{12}$	15300 MeV
(1/2, 1/2)	$\chi_8^{12}$	15400 MeV
(1/2, 1/2)	$\chi_9^{12}$	15500 MeV
(1/2, 1/2)	$\chi_1^{13}$	15600 MeV
(1/2, 1/2)	$\chi_2^{13}$	15700 Me

**Thanks for your attention!**