A Complete Tree-Level Dictionary between Simplified BSM Models and SMEFT ($d \leq 7$) Operators

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Based on work with Zhe Ren, Jiang-Hao Yu in preparation

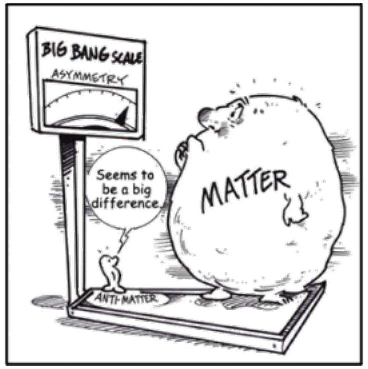
Outline

- EFT-based simplified models – A link between complete UV theory and effective theory
- Construct the UV-IR dictionary
- Examples:
  - Origin of neutrino mass
  - Neutrino-less double beta decay

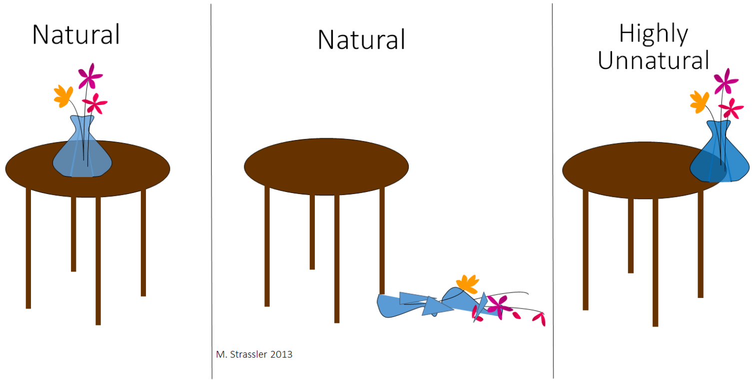
SMEFT: An Effective Way to Depict BSM Physics

Many phenomena indicate the existence of beyond the SM physics:

Neutrino Oscillation



Baryon Asymmetry of the Universe



The Hierarchy btw EW and Planck

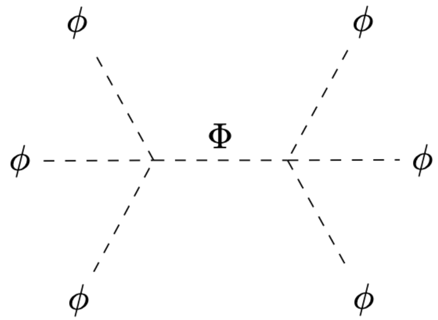
Some can be explained by introducing new heavy particles:

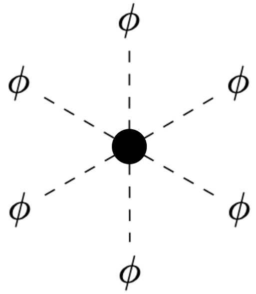
Seesaw models: Heavy neutrinos

CP violation: 2HDM, …

SUSY: SM particle partners

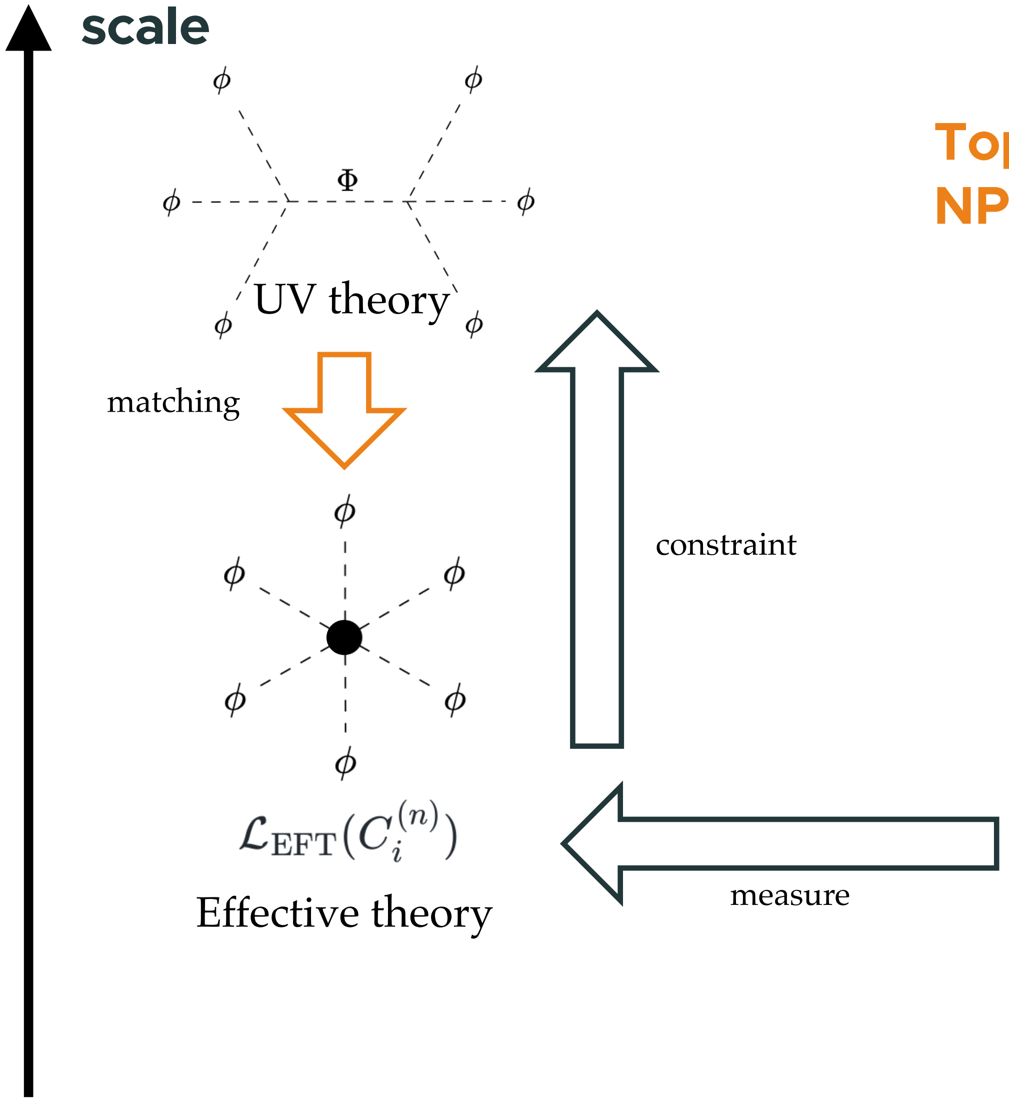
Suppose BSM physics is heavy, weakly-coupled, and obeys SM gauge symmetry



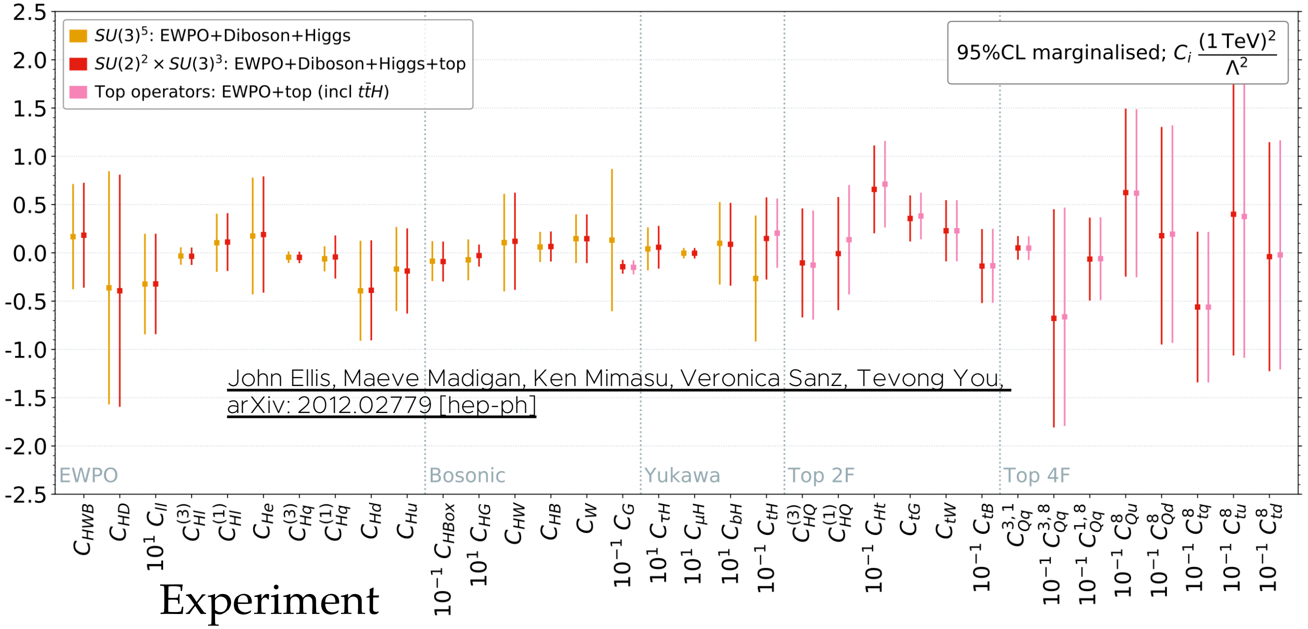


Linearly-realized $\mathcal{L}_{\rm EFT} = \mathcal{L}_{\rm SM} + \sum_i \frac{C_i^{(5)}}{\Lambda}\mathcal{O}_i^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \cdots$

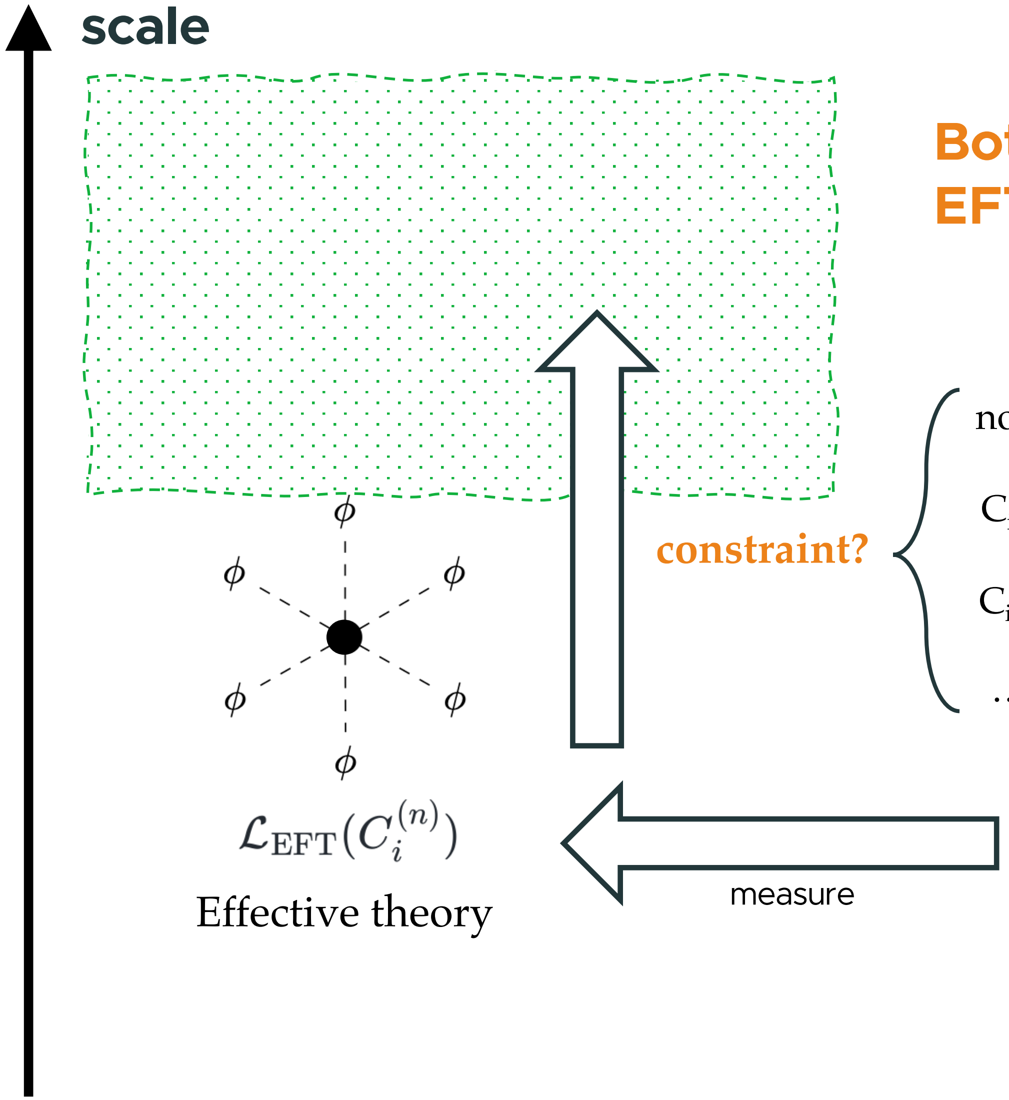
SMEFT in Top-Down



Top-down scenario :
NP-motivated simplified models



SMEFT in Bottom-Up



Bottom-up scenario :
EFT-based simplified model

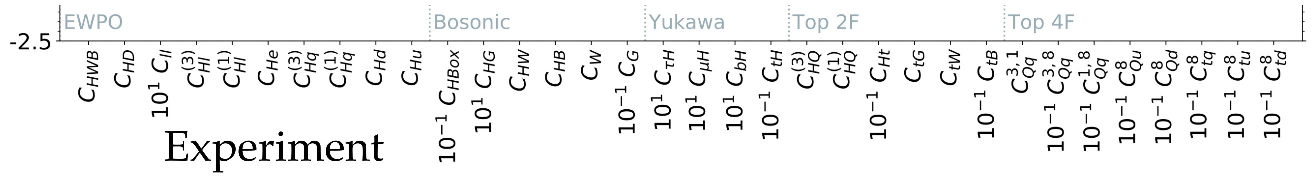
constraint?

- non-zero C_i
- $C_i > 0$
- $C_i = 3C_j$
- …

in

$$\mathcal{L}_{\mathrm{EFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{C_i^{(5)}}{\Lambda}\mathcal{O}_i^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_i \frac{C_i^{(7)}}{\Lambda^3}\mathcal{O}_i^{(7)} + \cdots$$

Dim-5	Dim-6	Dim-7
ν mass LNV: low-e exp	BLNC: Collider BNV: too heavy ~ 10^{16}GeV	ν mass w/ low Λ LNV: low-e exp



Experiment

Simplified Model: Enumerating

UV scale: Enumerate the fields and construct the Lagrangian

$$\mathcal{O}_5 = \epsilon^{ik}\epsilon^{jl}(\ell_i^T C \ell_j) H_k H_l$$

EFT Operators

Topologies

19 scalars, 14 fermions, 14 vectors

Field	(J, C, W, Y)
S_1	(0, 1, 1, 0)
…	…
S_6	(0, 1, 3, 1)
…	…
F_1	(1/2, 1, 1, 0)
…	…
F_5	(1/2, 1, 3, 0)
…	…

UV States

$$\Delta\mathcal{L}_{\text{int}} = \mathcal{C}^{p_1}_{HHS_6^\dagger} H_i H_j S^{\dagger,ij}_{6,p_1} - \mathcal{D}^{f_1 f_2 p_1}_{LLS_6} \epsilon^{ik}\epsilon^{jl} \bar{\ell}^c{}_{i,f_1} \ell_{j,f_2} S_{6,kl,p_1}$$
$$+\mathcal{D}^{p_1 p_2}_{HH^\dagger S_6 S_6^\dagger(1)} \epsilon^{ik}\epsilon_{jl} H_i H^{\dagger,j} S_{6,km,p_1} S^{\dagger,lm}_{6,p_2} + \mathcal{D}^{p_1 p_2}_{HH^\dagger S_6 S_6^\dagger(2)} H_i H^{\dagger,i} S_{6,jk,p_1} S^{\dagger,jk}_{6,p_2}$$
$$-\mathcal{D}^{p_1 f_1}_{F_1 HL}\epsilon^{ij}\bar{F}^c_{1\,p_1}\ell_{j,f_1} H_i - \mathcal{D}^{p_1 f_1}_{F_5 HL}\epsilon^{ik}\epsilon^{jl}\bar{F}^c_{5\,ij,p_1}\ell_{k,f_1} H_l - \mathcal{D}^{f1p1p2}_{e^\dagger F_5 S_6^\dagger}\bar{e}_{p_1} F_{5,ij,f_1} S^{\dagger,ij}_{6,p2} + \text{h. c.}$$

UV Lagrangian

Hao-Lin Li, Yu-Han Ni, Ming-Lei Xiao, Jiang-Hao Yu, arXiv: 2204.03660 [hep-ph]

Simplified Model: Matching

UV scale Lagrangian

$\mathcal{L}_{\text{UV}}[\phi, \Phi]$

Matching: Find $\mathcal{L}_{\text{EFT}}$ such that effective action $\Gamma_{\text{EFT}}[\phi] = \Gamma_{\text{UV}}[\phi]$

Tree-level:

$$\Gamma^{(0)}_{\text{UV}}[\phi] = \int \mathrm{d}^4x \mathcal{L}_{\text{UV}}[\phi, \Phi]\big|_{\Phi=\Phi_c[\phi]}, \quad \Gamma^{(0)}_{\text{EFT}}[\phi] = \int \mathrm{d}^4x \mathcal{L}_{\text{EFT}}[\phi] \Rightarrow \mathcal{L}_{\text{EFT}}[\phi] = \mathcal{L}_{\text{UV}}[\phi, \Phi]\big|_{\Phi=\Phi_c[\phi]}$$

Matching

$$\Delta\mathcal{L}_{\text{UV}} = -\Delta^{\dagger I}(D^2 + M^2)\Delta^I - \frac{\mu}{2}\left(H^T i\sigma^2\sigma^I\Delta^{\dagger I}H + \text{ h.c. }\right)$$

$$\Downarrow$$

$$\Delta^I_c = -\frac{\mu}{2M^2}\left(1 - \frac{D^2}{M^2}\right)H^T i\sigma^2\sigma^I H$$

$$\Delta\mathcal{L}_{\text{EFT}} = \frac{\mu^2}{2M^2}(H^\dagger H)^2 + \frac{\mu^2}{M^4}(H^\dagger D_\mu H)^*(H^\dagger D^\mu H) + \frac{\mu^2}{M^4}(H^\dagger H)(D_\mu H)^\dagger(D^\mu H)$$

NOT in Warsaw basis

Need to reduce the effective theory to a **non-redundant** form

Simplified Model: Reduction

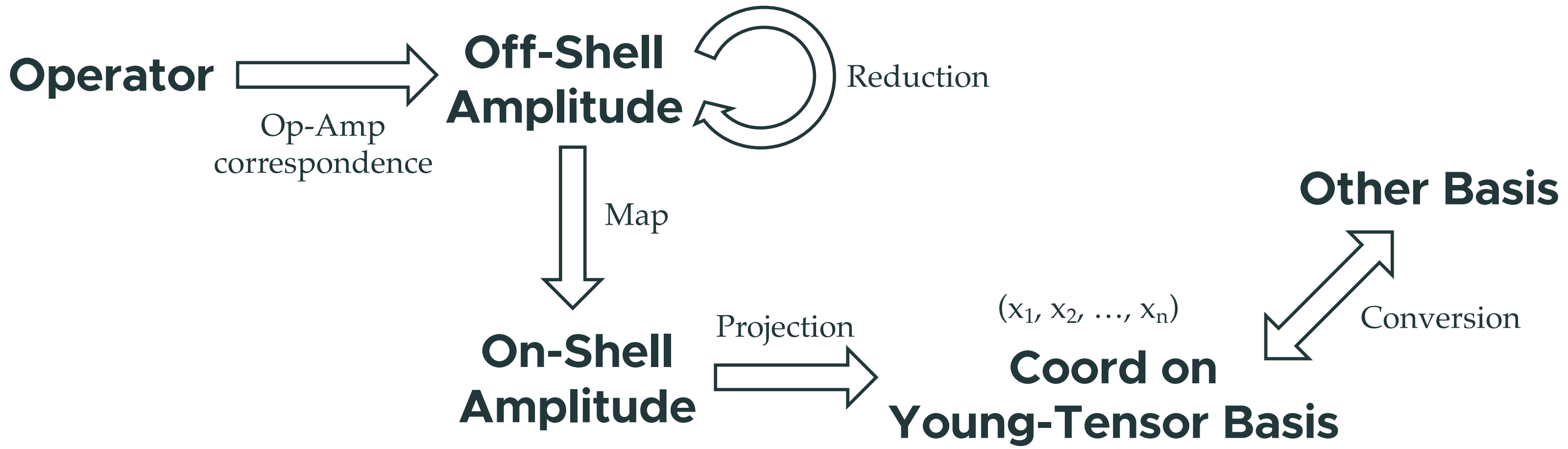
UV scale

Redundancies:

- Integration by part (momentum conservation) $(H^\dagger H)\Box(H^\dagger H), \quad \partial_\mu(H^\dagger H)\partial^\mu(H^\dagger H)$
- Group Identities $(\bar{\ell}_L\gamma_\mu\ell_L)(\bar{e}_R\gamma^\mu e_R), \quad (\bar{\ell}_L e_R)(\bar{e}_R\ell_L)$
- Contractor of covariant derivative $(D^\mu D^\nu H)^\dagger([D_\mu, D_\nu]H), \quad (D^\mu D^\nu H)^\dagger(X_{\mu\nu}H)$
- EOM replacement (field redefinition)

Matching & Reduction

$$-H^\dagger(D^2-\mu_H^2)H + (H^\dagger H)\left[\frac{c}{\Lambda^2}(D^2H)^\dagger H + \text{h.c.}\right] \xrightarrow{H \to H + \frac{c}{\Lambda^2}(H^\dagger H)H} -H^\dagger(D^2-\mu_H^2)H + \frac{2\,\text{Re}(c)}{\Lambda^2}\mu_H^2(H^\dagger H)^2 + \frac{|c|^2}{\Lambda^4}\mu_H^2(H^\dagger H)^3 + \cdots$$



EW scale

The UV-IR Dictionary

UV scale
Enumerating

1 scalar 2 fermions	19 scalars 13 fermions 14 vectors	12 scalars 14 fermions 5 vectors
d = 5	d = 6	d = 7

UV Lagrangian

Reduction

On-Shell Basis

Matching

Green's Basis

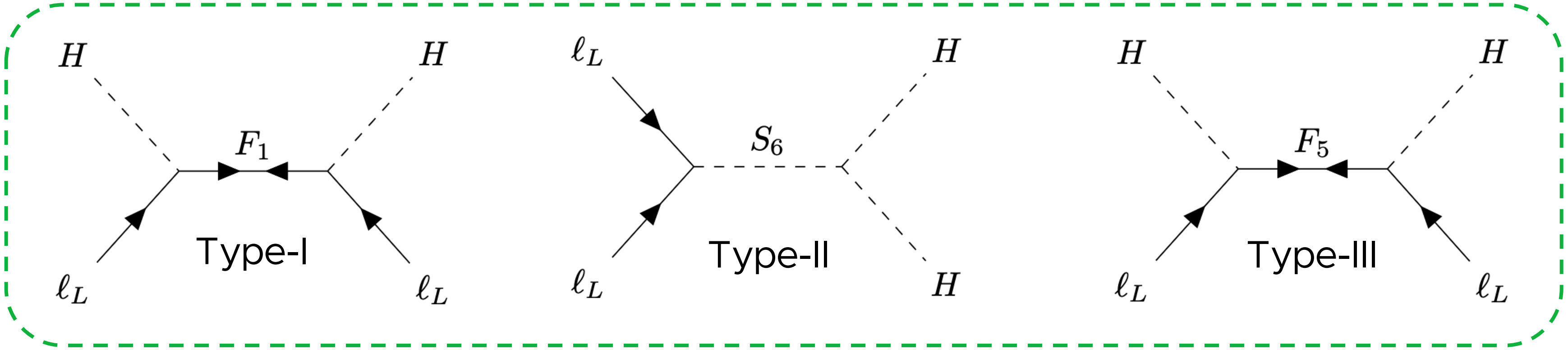
EW scale
Effective Theory

$$
\begin{array}{c|c|c|c|c|c|c}
 & d=5 & d=6 & & & d=7 & \\
\hline
d=5 & X & 0 & 0 & 0 & X & X \\
\hline
d=6 & 0 & X & X & X & X & X \\
 & 0 & X & X & X & X & X \\
 & 0 & X & X & X & X & X \\
 & 0 & X & X & X & X & X \\
 & 0 & X & X & X & X & X \\
\hline
d=7 & 0 & 0 & 0 & 0 & X & X \\
 & 0 & 0 & 0 & 0 & X & X \\
 & 0 & 0 & 0 & 0 & X & X
\end{array}
$$

$$
\begin{aligned}
O_{dLueH} = & \frac{8\mathcal{D}^{f_1p_1p_2*}_{dF^\dagger_{12R}V_3}\mathcal{D}^{f_4f_2p_2*}_{e^\dagger L^\dagger V_3^\dagger}\mathcal{D}^{p_1f_5*}_{F_{12L}H^\dagger u^\dagger}}{M_{F_{12}}M^2_{V_3}} - \frac{16\mathcal{D}^{f_1f_4p_1}_{d^\dagger eV_5}\mathcal{D}^{p_2f_5*}_{F_{12L}H^\dagger u^\dagger}\mathcal{D}^{p_2f_2p_1*}_{F^\dagger_{12R}L^\dagger V_5}}{M_{F_{12}}M^2_{V_5}} \\
& + \frac{8\mathcal{D}^{f_1f_4p_1}_{d^\dagger eV_5}\mathcal{D}^{p_2f_2}_{F_1HL}\mathcal{D}^{p_2f_5p_1*}_{F_1^\dagger u^\dagger V_5}}{M_{F_1}M^2_{V_5}} + \frac{32\mathcal{D}^{f_1f_4p_1}_{d^\dagger eV_5}\mathcal{D}^{f_2f_5p_2*}_{L^\dagger u^\dagger V_8}\mathcal{C}^{p_1p_2}_{HV_5^\dagger V_8}}{M^2_{V_5}M^2_{V_8}} \\
& + \frac{16\mathcal{D}^{f_1p_1}_{d^\dagger F_{10L}H}\mathcal{D}^{f_4p_1p_2}_{eF^\dagger_{10R}V_8}\mathcal{D}^{f_2f_5p_2*}_{L^\dagger u^\dagger V_8}}{M_{F_{10}}M^2_{V_8}} + \frac{8\mathcal{D}^{f_1p_1}_{d^\dagger F_{10L}H}\mathcal{D}^{f_4f_2p_2*}_{e^\dagger L^\dagger V_3^\dagger}\mathcal{D}^{p_1f_5p_2}_{F^\dagger_{10R}uV_3^\dagger}}{M_{F_{10}}M^2_{V_3}} \\
& + \frac{8\mathcal{D}^{f_1p_1}_{d^\dagger F_{10L}H}\mathcal{D}^{f_4p_2f_5*}_{e^\dagger S_{10}u^\dagger}\mathcal{D}^{p_1f_2p_2}_{F^\dagger_{10R}LS_{10}}}{M_{F_{10}}M^2_{S_{10}}} + \frac{4\mathcal{D}^{f_1p_1p_2}_{d^\dagger F_1S_{10}}\mathcal{D}^{f_4p_2f_5*}_{e^\dagger S_{10}u^\dagger}\mathcal{D}^{p_1f_2}_{F_1HL}}{M_{F_1}M^2_{S_{10}}} \\
& - \frac{8\mathcal{D}^{f_1p_1p_2}_{d^\dagger F^\dagger_{3L}V_8}\mathcal{D}^{f_4p_1*}_{e^\dagger F^\dagger_{3R}H^\dagger}\mathcal{D}^{f_2f_5p_2*}_{L^\dagger u^\dagger V_8}}{M_{F_3}M^2_{V_8}} + \frac{8\mathcal{D}^{f_1f_2p_1}_{d^\dagger LS_{12}}\mathcal{D}^{f_4p_2p_1*}_{e^\dagger F^\dagger_{12R}S_{12}}\mathcal{D}^{p_2f_5*}_{F_{12L}H^\dagger u^\dagger}}{M_{F_{12}}M^2_{S_{12}}} \\
& - \frac{4\mathcal{D}^{f_1f_2p_1}_{d^\dagger LS_{12}}\mathcal{D}^{f_4p_2*}_{e^\dagger F^\dagger_{3R}H^\dagger}\mathcal{D}^{p_2p_1f_5*}_{F_{3L}S_{12}u^\dagger}}{M_{F_3}M^2_{S_{12}}} + \frac{8\mathcal{D}^{f_1f_2p_1}_{d^\dagger LS_{12}}\mathcal{D}^{f_4p_2f_5*}_{e^\dagger S_{10}u^\dagger}\mathcal{C}^{p_2p_1}_{HS_{10}S^\dagger_{12}}}{M^2_{S_{10}}M^2_{S_{12}}} \\
& + \frac{4\mathcal{D}^{f_1f_5p_1}_{d^\dagger uV_2^\dagger}\mathcal{D}^{f_4p_2p_1}_{eF_1V_2}\mathcal{D}^{p_2f_2}_{F_1HL}}{M_{F_1}M^2_{V_2}} + \frac{4\mathcal{D}^{f_1f_5p_1}_{d^\dagger uV_2^\dagger}\mathcal{D}^{f_4p_2*}_{e^\dagger F^\dagger_{3R}H^\dagger}\mathcal{D}^{p_2f_2p_1*}_{F_{3L}L^\dagger V_2^\dagger}}{M_{F_3}M^2_{V_2}} \\
& - \frac{8\mathcal{D}^{f_1f_5p_1}_{d^\dagger uV_2^\dagger}\mathcal{D}^{f_4f_2p_2*}_{e^\dagger L^\dagger V_3^\dagger}\mathcal{C}^{p_1p_2}_{HV_2V_3^\dagger}}{M^2_{V_2}M^2_{V_3}}
\end{aligned}
$$

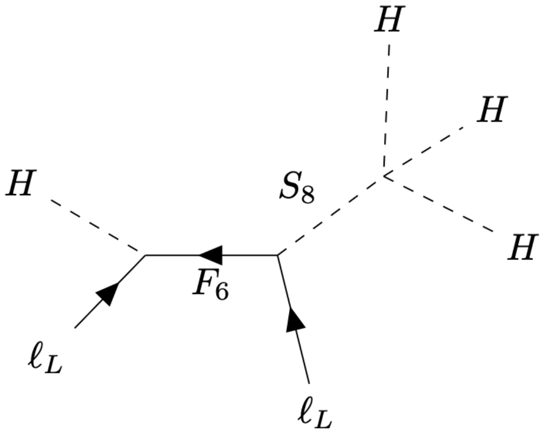
Example 1: Origin of neutrino mass

Three seesaw models that could generate the neutrino mass (via Weinberg operator):



$$\mathcal{O}_5 = \epsilon^{ik}\epsilon^{jl}(\ell_i^T C \ell_j) H_k H_l$$

Field	(SU(3), SU(2), U(1))
S_8	(1, 3, 3/2)
F_6	(1, 2, 1)



$$\mathcal{O}_{LH} = \epsilon^{ik}\epsilon^{jl}(\ell_i^T C \ell_j) H_k H_l H_m H^{\dagger,m}$$

Example 1: Origin of neutrino mass

Operators	F_1	S_6	F_5	S_8/F_6	m_ν	$0\nu\beta\beta$	other
$\mathcal{O}_5$	✓	✓	✓	✗	0	✓	
$\mathcal{O}_H$	✗	✓	✗	✓	collider/ low-energy		
$\mathcal{O}_{H\Box}$	✗	✓	✗	✗			
$\mathcal{O}_{HD}$	✗	✓	✗	✗			
$\mathcal{O}_{eH}$	✗	✓	✓	✗			
$\mathcal{O}_{uH}$	✗	✓	✗	✗			
$\mathcal{O}_{dH}$	✗	✓	✗	✗			
$\mathcal{O}_{Hl}^{(1)}$	✓	✗	✓	✓			
$\mathcal{O}_{Hl}^{(3)}$	✓	✗	✓	✓			
$\mathcal{O}_{ll}$	✗	✓	✗	✗			
$\mathcal{O}_{LH}$	✓	✓	✓	✓	0	✓	τ
$\mathcal{O}_{LeHD}$	✓	✗	✗	✗	1	✓	τ
$\mathcal{O}_{LHD1}$	✗	✓	✓	✗	1	✓	τ, K
$\mathcal{O}_{LHD2}$	✓	✓	✗	✗	1	✗	τ
$\mathcal{O}_{LHW}$	✓	✗	✓	✗	1	✓	τ, K, Dip
$\mathcal{O}_{LHB}$	✗	✗	✗	✗	2	✗	Dip
$\mathcal{O}_{eLLLH}$	✓	✗	✓	✗	1	✗	τ
$\mathcal{O}_{dLQLH1}$	✓	✗	✓	✗	1	✓	τ
$\mathcal{O}_{dLQLH2}$	✓	✗	✓	✗	2	✓	τ
$\mathcal{O}_{QuLLH}$	✓	✗	✓	✗	1	✓	τ

✓/✗ : can/cannot be generated at tree level

$$C_{LHW} = \frac{g}{M_{F_5}^2} C_5$$

$\tau : \tau^+ \to \ell^- \pi^+ \pi^+$

$K : K^\pm \to \pi^\mp \ell^\pm \ell^\pm$

Type: $\psi^2 H^2$	
$\mathcal{O}_5$	$\epsilon^{ik}\epsilon^{jl}(\ell_i^T C \ell_j) H_k H_l$

Warsaw basis			
$\mathcal{O}_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$	$\mathcal{O}_{eH}$	$(H^\dagger H)(\bar{\ell} e H)$
$\mathcal{O}_{HD}$	$(H^\dagger D^\mu H)^*(H^\dagger D^\mu H)$	$\mathcal{O}_{uH}$	$(H^\dagger H)(\bar{q} u \tilde{H})$
$\mathcal{O}_H$	$(H^\dagger H)^3$	$\mathcal{O}_{dH}$	$(H^\dagger H)(\bar{q} d H)$
$\mathcal{O}_{H\ell}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{\ell}\gamma^\mu \ell)$	$\mathcal{O}_{\ell\ell}$	$(\bar{\ell}\gamma^\mu \ell)(\bar{\ell}\gamma_\mu \ell)$
$\mathcal{O}_{H\ell}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{\ell}\tau^I\gamma^\mu \ell)$		

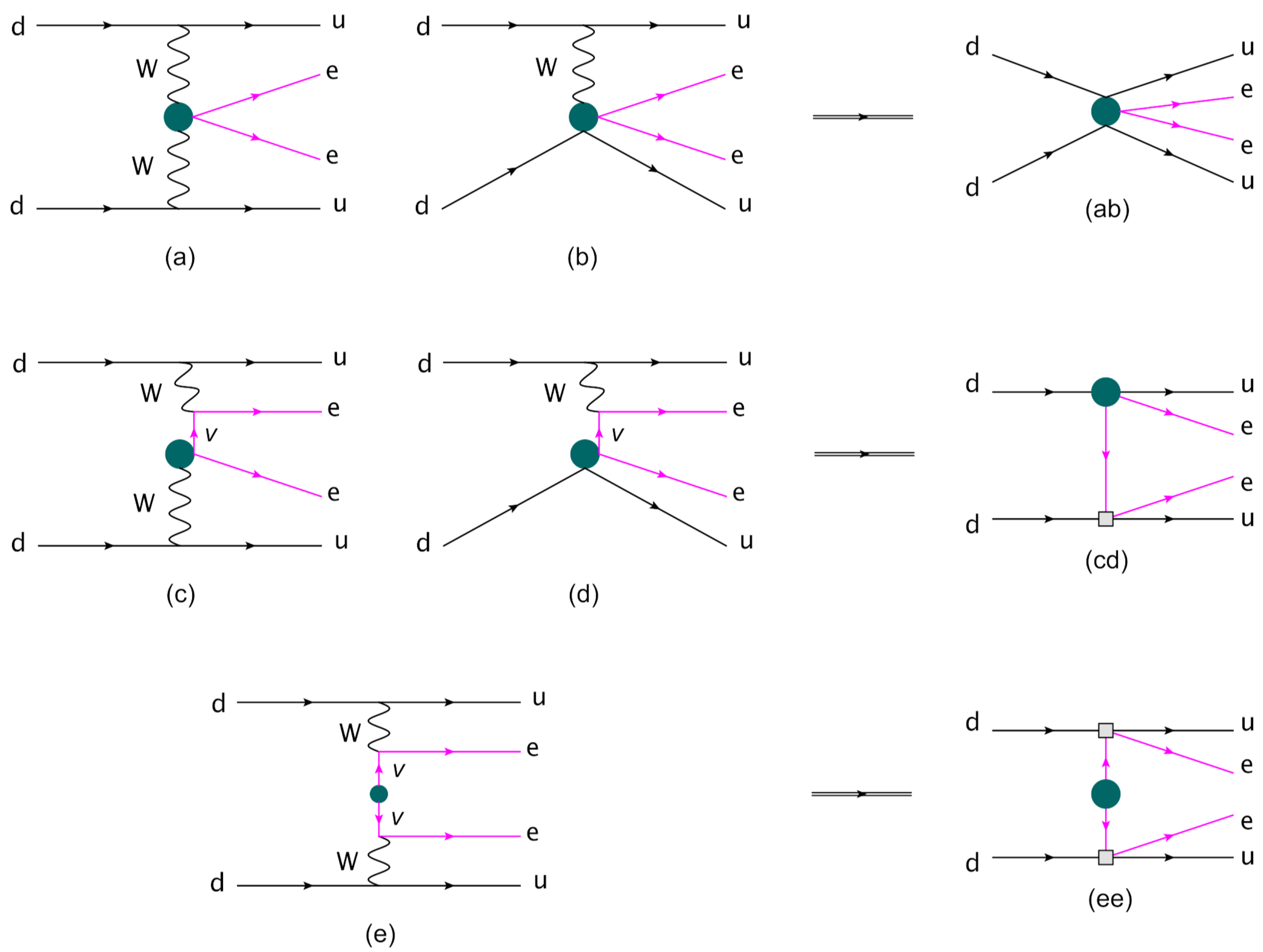
Only L-violating			
Type: $\psi^2 H^4$		Type: $\psi^2 H^3 D$	
$\mathcal{O}_{LH}$	$\epsilon^{ik}\epsilon^{jl}(\ell_i^T C \ell_j) H_k H_l (H^\dagger H)$	$\mathcal{O}_{LeHD}$	$\epsilon^{ij}\epsilon^{kl}(\ell_i^T C \gamma^\mu e) H_j H_k (i D_\mu H_l)$
Type: $\psi^2 H^2 D^2$		Type: $\psi^2 H^2 X$	
$\mathcal{O}_{LDH1}$	$\epsilon^{ij}\epsilon^{kl}(\ell_i^T C D_\mu \ell_j)(H_k D^\nu H_l)$	$\mathcal{O}_{LHW}$	$-\epsilon^{ik}(\epsilon\tau^I)^{jl}(\ell_i^T C i\sigma^{\mu\nu}\ell_j) H_k H_l W_{\mu\nu}^I$
$\mathcal{O}_{LDH2}$	$\epsilon^{ik}\epsilon^{jl}(\ell_i^T C D_\mu \ell_j)(H_k D^\nu H_l)$	$\mathcal{O}_{LHB}$	$\epsilon^{ik}\epsilon^{jl}(\ell_i^T C i\sigma^{\mu\nu}\ell_j) H_k H_l B_{\mu\nu}$
Type: $\psi^4 D$		Type: $\psi^4 H$	
$\mathcal{O}_{duLLD}$	$\epsilon^{ij}(\bar{d}^a \gamma^\mu u_a)(\ell_i^T C i D_\mu \ell_j)$	$\mathcal{O}_{eLLLH}$	$\epsilon^{ij}\epsilon^{kl}(\bar{e}\ell_i)(\ell_j^T C \ell_k) H_l$
		$\mathcal{O}_{dLQLH1}$	$\epsilon^{ij}\epsilon^{kl}(\bar{d}^a \ell_i)(q_{aj}^T C \ell_k) H_l$
		$\mathcal{O}_{dLQLH2}$	$\epsilon^{ik}\epsilon^{jl}(\bar{d}^a \ell_i)(q_{aj}^T C \ell_k) H_l$
		$\mathcal{O}_{dLueH}$	$\epsilon^{ij}(\bar{d}^a \ell_i)(u_a^T C e) H_j$
		$\mathcal{O}_{QuLLH}$	$\epsilon^{ij}(\bar{q}^{ak} u_a)(\ell_k^T C \ell_i) H_j$

Loop:

Xu Li, Di Zhang, Shun Zhou, arXiv: 2201.05082 [hep-ph]

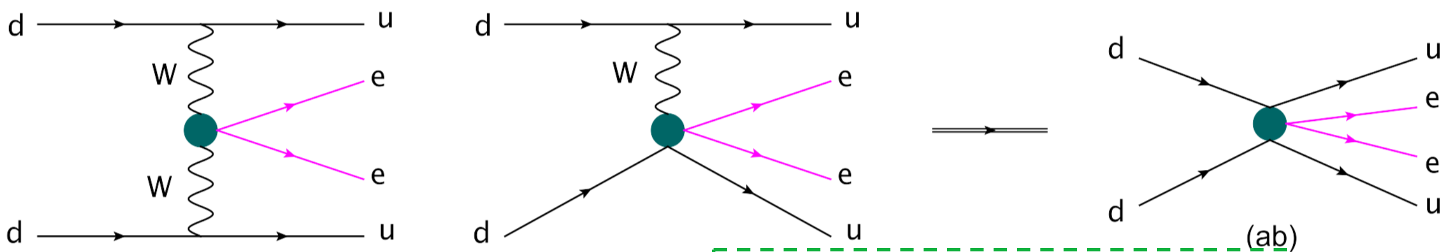
Yong Du, Xu-Xiang Li, Jiang-Hao Yu, arXiv: 2201.04646 [hep-ph]

Example 2: Neutrino-less double beta decay



V. Cirigliano, W. Dekens, J. de Vries, M.L. Graesser, E. Mereghetti
arXiv: 1708.09390 [hep-ph]
Yi Liao, Xiao-Dong Ma
arXiv: 1901.10302 [hep-ph]

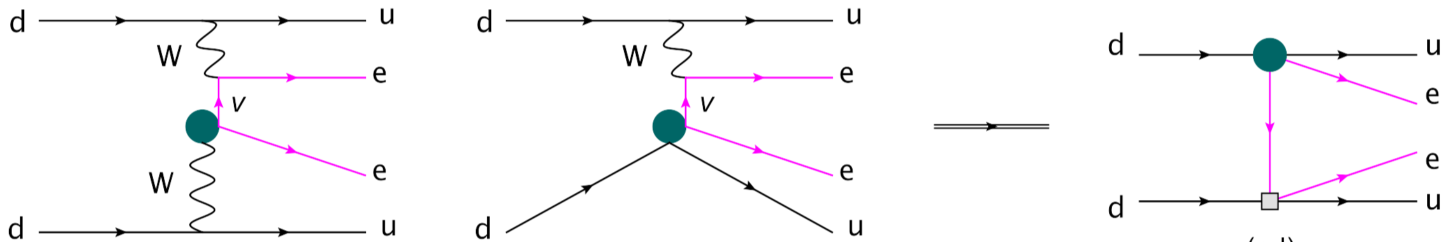
Example 2: Neutrino-less double beta decay



(a) (b) (ab)

$\mathcal{O}_{LHD1}$	$\epsilon^{ij}\epsilon^{kl}(\ell_i^T C D_\mu \ell_j)(H_k D^\nu H_l)$

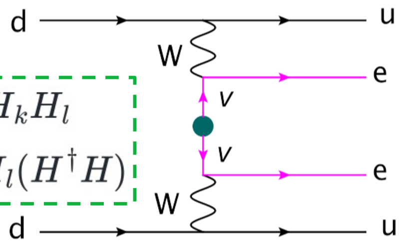
$\mathcal{O}_{duLLD}$	$\epsilon^{ij}(\bar{d}^a \gamma^\mu u_a)(\ell_i^T C i D_\mu \ell_j)$



(c) (d) (cd)

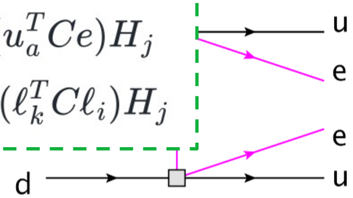
$\mathcal{O}_{LeHD}$	$\epsilon^{ij}\epsilon^{kl}(\ell_i^T C\gamma^\mu e)H_j H_k(iD_\mu H_l)$
$\mathcal{O}_{LHW}$	$-\epsilon^{ik}(\epsilon\tau^I)^{jl}(\ell_i^T C i\sigma^{\mu\nu}\ell_j)H_k H_l W^I_{\mu\nu}$

$\mathcal{O}_{dLQLH1}$	$\epsilon^{ij}\epsilon^{kl}(\bar{d}^a \ell_i)(q_{aj}^T C\ell_k)H_l$
$\mathcal{O}_{dLQLH2}$	$\epsilon^{ik}\epsilon^{jl}(\bar{d}^a \ell_i)(q_{aj}^T C\ell_k)H_l$
$\mathcal{O}_{dLueH}$	$\epsilon^{ij}(\bar{d}^a \ell_i)(u_a^T Ce)H_j$
$\mathcal{O}_{QuLLH}$	$\epsilon^{ij}(\bar{q}^{ak} u_a)(\ell_k^T C\ell_i)H_j$



(e)

$\mathcal{O}_5$	$\epsilon^{ik}\epsilon^{jl}(\ell_i^T C\ell_j)H_k H_l$
$\mathcal{O}_{LH}$	$\epsilon^{ik}\epsilon^{jl}(\ell_i^T C\ell_j)H_k H_l(H^\dagger H)$



(ee)

Example 2: Neutrino-less double beta decay

B preserving		B preserving		B violating	
$(S,1,1,1)$	$(S,1,2,1/2)$	$(S,3,2,1/6)$	$(F,3,2,7/6)$	$(S,3,1,-1/3)$	$(S,3,2,1/6)$
$(S,3,2,1/6)$	$(S,3,3,-1/3)$	$(S,3,2,1/6)$	$(F,3,3,2/3)$	$(S,3,1,-1/3)$	$(F,3,2,-5/6)$
$(S,1,1,1)$	$(F,3,1,-1/3)$	$(S,3,3,-1/3)$	$(F,3,2,-5/6)$	$(V,3,2,1/6)$	$(F,1,2,1/2)$
$(S,1,1,1)$	$(F,3,1,2/3)$	$(V,1,1,1)$	$(F,1,2,1/2)$	$(V,3,2,1/6)$	$(F,3,1,-1/3)$
$(S,1,1,1)$	$(F,3,2,-5/6)$	$(V,1,2,3/2)$	$(F,3,2,-5/6)$	$(V,3,2,1/6)$	$(F,3,2,-5/6)$
$(S,1,1,1)$	$(F,3,2,7/6)$	$(V,1,2,3/2)$	$(F,3,2,7/6)$	$(V,3,2,1/6)$	$(F,3,3,-1/3)$
$(S,1,2,1/2)$	$(F,1,3,0)$	$(V,3,1,2/3)$	$(F,3,2,7/6)$	$(V,3,1,2/3)$	$(V,3,2,1/6)$
$(S,3,2,1/6)$	$(F,1,2,1/2)$	$(V,3,3,3/2)$	$(F,3,2,7/6)$	$(V,3,2,1/6)$	$(V,3,3,2/3)$
$(S,3,2,1/6)$	$(F,3,1,2/3)$	$(V,1,1,1)$	$(V,1,2,3/2)$		

18 B preserving UV + 8 B violating UV

($0\nu\beta\beta$ w/ no tree ν-mass)

Example 2: Neutrino-less double beta decay

scale

Suppose O_{dLueH} is measured by low-energy experiments…

UV scale

EFT-based simplified model

Field	(SU(3), SU(2), U(1))
S_{12}	(3, 2, 1/6)
F_{12}	(3, 2, 7/6)

Find possible UV

Find effective theory

EW scale

$\mathcal{O}_{dLueH}$

0νββ
1-loop ν mass

$\mathcal{O}_{ld}, \mathcal{O}_{uH}, \mathcal{O}_{Hu}, \mathcal{O}_{dLueH}$ with relation

d = 6
collider
measurement

$$|\mathcal{C}^{f_1 f_2 f_4 f_5}_{dLueH}|^2 = \frac{16}{M^2_{S_{12}}} |\mathcal{D}^{f_4}_{e^\dagger F^\dagger_{12R} S_{12}}|^2 C^{f_1 f_2 f_1 f_2}_{ld} C^{f_5 f_5}_{Hu}$$

$$C^{f_4 f_5}_{uH} = y^{f_4 p_1}_u C^{p_1 f_5}_{Hu}$$

Summary

- The UV-IR dictionary can be used as combined searches by means of both high energy colliders and low energy experiments
- Relations between same/different-dimension operators may contain rich interesting physical origins
- We also provide a systematic way to reduce operator to any basis

Thank you!

Backup

The Fermion Only Contributes to d = 7

Field	(SU(3), SU(2), U(1))
S_2	(1, 1, 1)
F_4	(1, 2, 3/2)

$\mathcal{O}_{ll}, \mathcal{O}_{eLLLH}$

Field	(SU(3), SU(2), U(1))
S_6	(1, 3, 0)
F_4	(1, 2, 3/2)

$\mathcal{O}_{H,H\Box,HD}, \mathcal{O}_{eH,dH,uH}, \mathcal{O}_{eLLLH}$

	^{76}Ge	^{82}Se	^{130}Te	^{136}Xe	^{76}Ge	^{82}Se	^{130}Te	^{136}Xe	^{76}Ge	^{82}Se	^{130}Te	^{136}Xe
$\mathcal{C}^{(1)}_{LHD}$	15	6.9	11	13	13	6.6	9.9	16	12	5.9	11	17
$\mathcal{C}_{LHDe}$	160	73	130	200	130	65	98	160	120	61	110	180
$\mathcal{C}_{LHW}$	23	11	17	20	20	11	16	26	18	9.4	17	28
$\mathcal{C}^{(1)}_{LLduD}$	74	35	65	95	56	29	42	72	54	27	49	78
$\mathcal{C}^{(1)}_{LLQdH}$	240	110	200	320	200	100	140	250	180	93	160	270
$\mathcal{C}^{(2)}_{LLQdH}$	120	58	100	150	99	51	77	130	94	48	85	140
$\mathcal{C}_{LLQuH}$	310	150	260	410	250	130	180	300	230	120	210	340
$\mathcal{C}_{Leu\bar{d}H}$	29	15	26	39	24	14	18	30	23	13	22	35

Table 7: The table shows the lower limits on the scale of the dimension-seven couplings, from the GERDA [87], NEMO [9, 11], CUORE [7], and KamLAND-Zen [13] experiments, assuming $\mathcal{C}_i(\mu = \Lambda) = 1/\Lambda^3$. The left, middle, and right tables correspond to the matrix elements of Refs. [76], [32], and [83], respectively. The limits on Λ are shown in units of TeV.

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