SMEFT Dimension-8 Renormalization

LoopFest XXIV, Brookhaven National Lab

May 27—29, 2026

Supratim Das Bakshi | sdasbakshi@anl.gov

Division of High Energy Physics,
Argonne National Laboratory (USA)

SMEFT Renormalization Status (2026)!

$$L_{\text{SMEFT}} = L_{\text{SM}} + \frac{d_5}{\Lambda} + \frac{d_6}{\Lambda^2} + \frac{d_7}{\Lambda^3} + \frac{d_8}{\Lambda^4} + \ldots$$

Gauge symmetry unbroken

1-loop	d_5	d_5^2	d_6	d_5^3	$d_5 \times d_6$	d_7	d_5^4	$d_5^2 \times d_6$	d_6^2	$d_5 \times d_7$	d_8
$d_{\leq 4}$ (bosonic)			✓						✓		This talk
$d_{\leq 4}$ (fermionic)			✓						✓		X
d_5	✓				✓	✓					
d_6 (bosonic)		✓	✓					✓	✓	✓	This talk
d_6 (fermionic)		✓	✓					X	✓	X	X
d_7				✓	✓	✓					
d_8 (bosonic)							This talk	This talk	This talk	This talk	This talk
d_8 (fermionic)							X	X	✓	X	✓

Blank entries vanish; ✓ $\rightarrow$ known; X $\rightarrow$ nothing, or very little, is known. The contribution discussed in this talk is marked by ■.

Table compiled from: arxiv:2106.05291, 2205.03301, 2301.07151, 2409.15408 . Check these out for Refs.

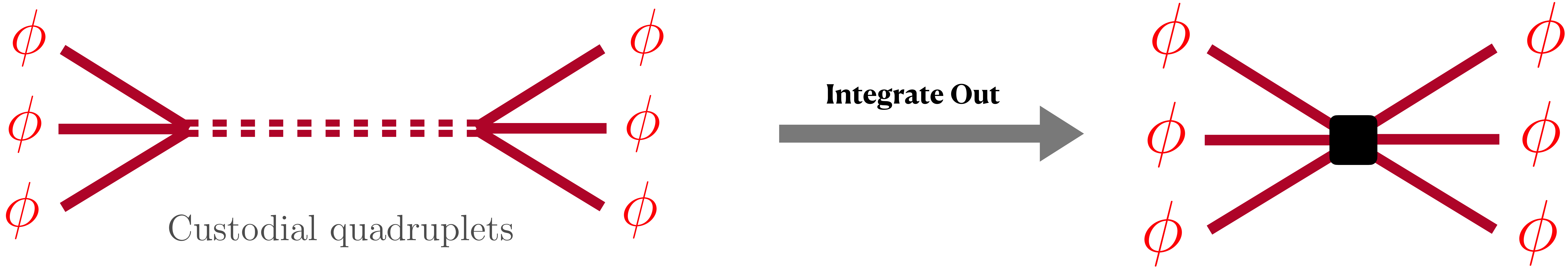
Authors: SDB, M. Chala, A. Diaz-Carmona, G. Guedes, M. Ramos, Z. Ren, J. Santiago, F. Vilches

Motivations :

- **RGEs reveal restrictions on Dim-8 WC space imposed from positivity bounds.**

Chala, Xu (2309.16611)

- **Custodial symmetry violation absent at tree-level dim-6, dim-8, and 1-loop dim-6.**



Chala, Krause, Nardini, (1802.02168); Durieux, McCullough, Salvioni (2209.00666)

- **Also, Dim-8 RGEs computed using multiple computational tools, with agreement in results. These establish validation among these tools.**

SMEFT Dim-8 RGEs

$\Lambda = \text{EFT cut-off scale}$

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\sum_i c_i^{(5)} O_i^{(5)} + \frac{1}{\Lambda^2}\sum_i c_i^{(6)} O_i^{(6)} + \frac{1}{\Lambda^3}\sum_j c_j^{(7)} O_j^{(7)} + \frac{1}{\Lambda^4}\sum_j c_j^{(8)} O_j^{(8)} + \cdots$$

$$\dot{c}_i^{(8)} \equiv 16\pi^2 \tilde{\mu} \frac{dc_i^{(8)}}{d\tilde{\mu}} = \boxed{\gamma_{ij} c_j^{(8)}} + \gamma'_{ijk} c_j^{(7)} c_k^{(5)} + \gamma''_{ijklm} c_j^{(5)} c_k^{(5)} c_l^{(5)} c_m^{(5)} + \ldots$$

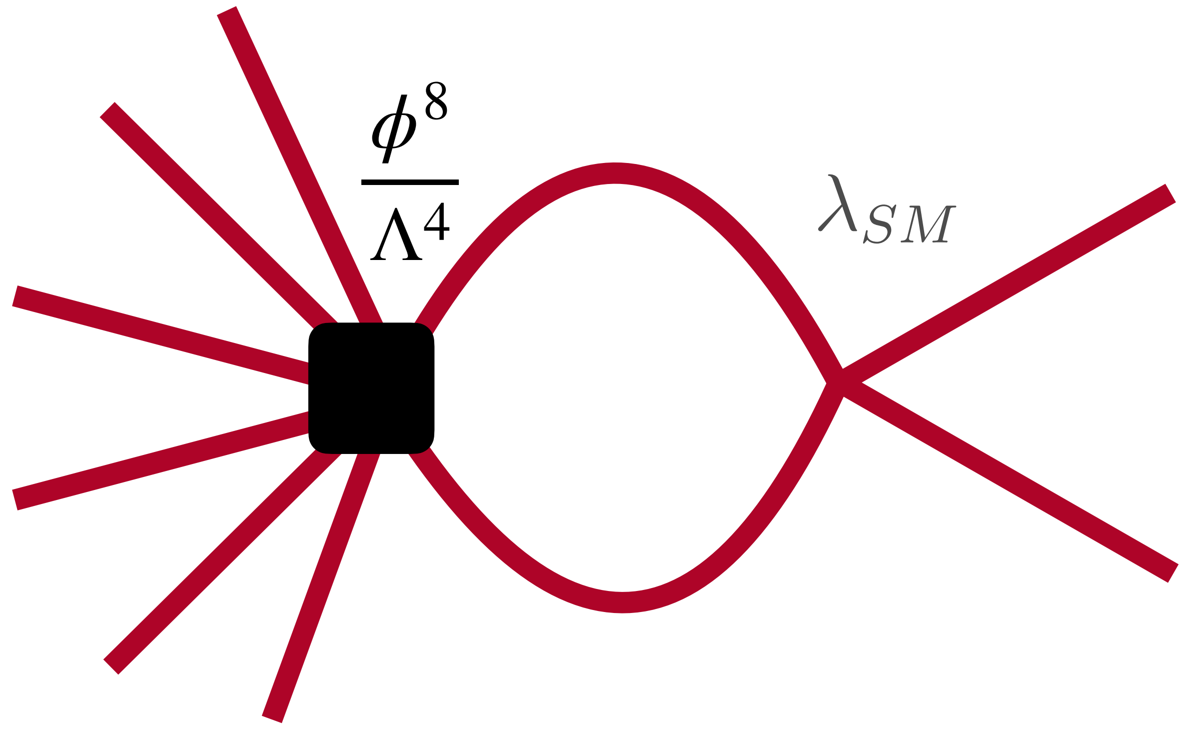
- One dim-8 operator insertion.

arXiv:2205.03301

Towards the renormalisation of the Standard Model effective field theory to dimension eight: Bosonic interactions II

- SDB, M Chala, Á Díaz-Carmona, G Guedes

e.g. :



Bosonic SMEFT Dim-8 RGEs

Λ = EFT cut-off scale

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\sum_i c_i^{(5)} O_i^{(5)} + \frac{1}{\Lambda^2}\sum_i c_i^{(6)} O_i^{(6)} + \frac{1}{\Lambda^3}\sum_j c_j^{(7)} O_j^{(7)} + \frac{1}{\Lambda^4}\sum_j c_j^{(8)} O_j^{(8)} + \cdots$$

$$\dot{c}_i^{(8)} \equiv 16\pi^2 \tilde{\mu}\frac{dc_i^{(8)}}{d\tilde{\mu}} = \gamma_{ij} c_j^{(8)} + \boxed{\gamma'_{ijk} c_j^{(7)} c_k^{(5)} + \gamma''_{ijklm} c_j^{(5)} c_k^{(5)} c_l^{(5)} c_m^{(5)}} + \ \ldots$$

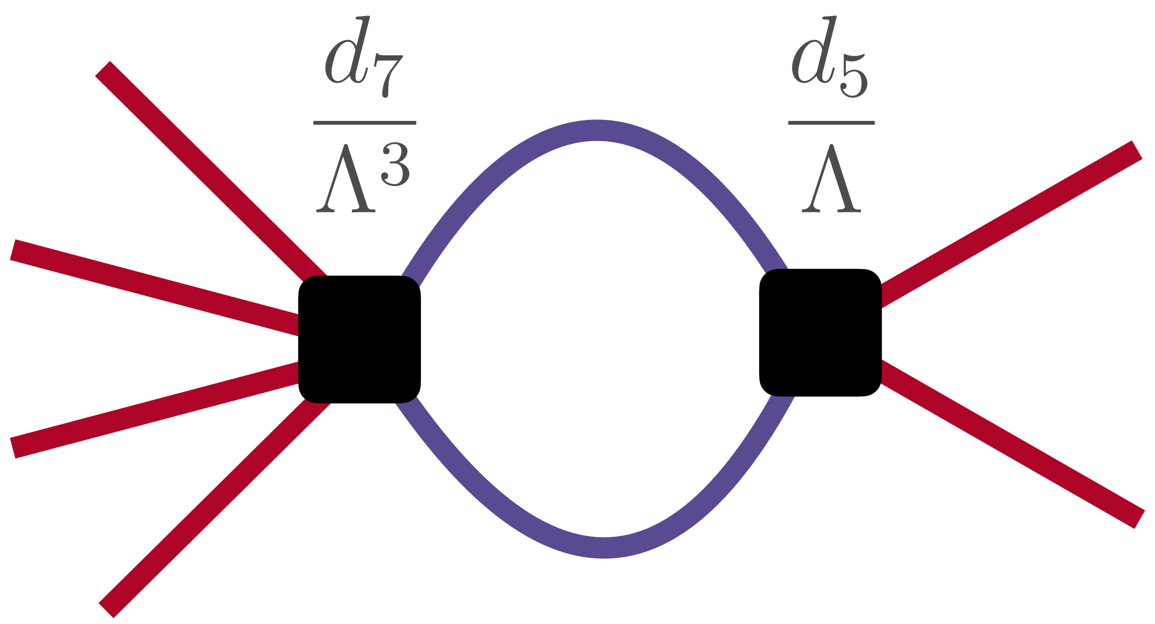
❖ Dim-7 and dim-5 operators insertions.

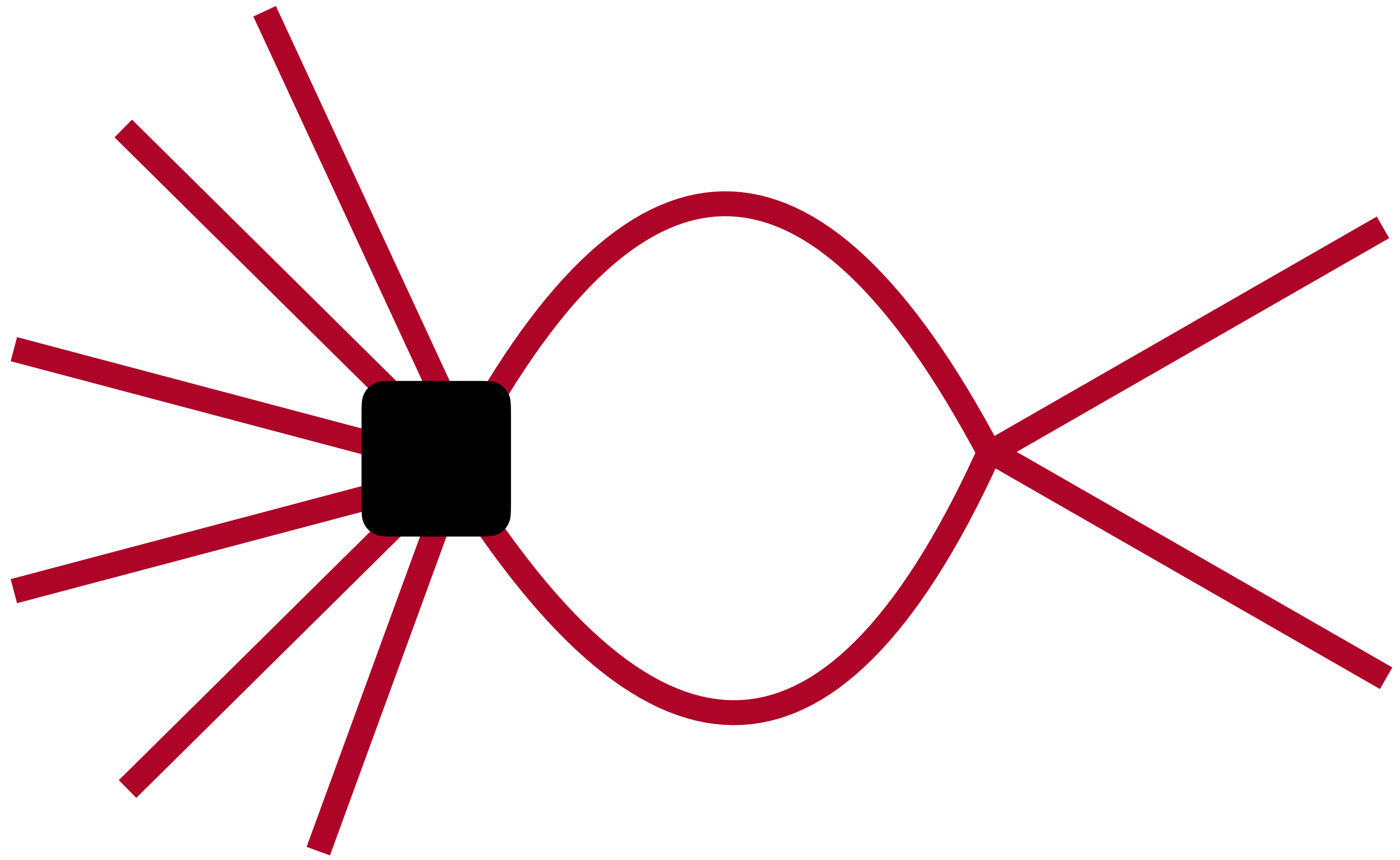
arXiv:2301.07151

Renormalisation of SMEFT bosonic interactions up to dimension eight by LNV operators

- SDB, Á Díaz-Carmona

e.g. :





Part 1 : Dim-8 renormalization by Dim-8

arXiv:2301.07151

arXiv:2409.15408

arXiv:2607.xxxxx

SMEFT Operator Classes

$$\dot{c}_i^{(8)} \equiv 16\pi^2 \tilde{\mu} \frac{dc_i^{(8)}}{d\tilde{\mu}} = \boxed{\gamma_{ij} c_j^{(8)}} + \gamma'_{ijk} c_j^{(7)} c_k^{(5)} + \gamma''_{ijklm} c_j^{(5)} c_k^{(5)} c_l^{(5)} c_m^{(5)} + \ldots$$

- One **tree-level generated** dim-8 operator in one-loop.

Classes of operator that are tree-level generated:

arXiv:2001.00017
- Craig, Jiang, Li, Sutherland

Bosonic : $\{\phi^8, \phi^6 D^2, \phi^4 D^4, X^2 \phi^4, X \phi^4 D^2, X^2 H^2 D^2, X^3 H^2, X^4\}$

Fermionic : $\{\psi^2 X \phi^3, \psi^2 \phi^2 D^3, \psi^2 \phi^5, \psi^2 \phi^4 D, \psi^2 X \phi^2 D, \psi^2 \phi^3 D^2, \psi^2 X^2 \phi, \psi^2 X^2 D, \psi^2 X \phi D^2\}$

SMEFT Dim-8 **on-shell basis** : arXiv:2005.00059 — C. W. Murphy

SMEFT Dim-8 **Green's basis** : arXiv:2112.12724 — M. Chala, Á Díaz-Carmona, G. Guedes

Divergences to RGEs, some details:

- Compute **1-PI loop diagrams**. Use **FeynRules, FeynARTs,** and **FormCalc** packages.

- Divergences are captured by the operators of **Green's basis.**

$$16\pi^2\epsilon\,\mathcal{L}_{\text{DIV}} = \tilde{K}_\phi (D_\mu\phi)^\dagger(D^\mu\phi) + \tilde{\mu}^2|\phi|^2 - \tilde{\lambda}|\phi|^4 + \tilde{c}_i^{(6)}\frac{\mathcal{O}_i^{(6)}}{\Lambda^2} + \tilde{c}_j^{(8)}\frac{\mathcal{O}_j^{(8)}}{\Lambda^4}$$

arXiv:2112.12724
- M Chala, Á Díaz-Carmona, G Guedes

[on RHS we have Green's basis]

- **Removing redundant operators** using EOMs (e.g. $(H^\dagger H)(H^\dagger D^2 H)$) .

arXiv:2106.05291- M Chala, G Guedes, M Ramos, J Santiago

- **Cross-checks with MatchMakerEFT.** ✓
  H^8 topologies are computed in MM primarily.

arXiv:2112.10787
- A Carmona, A Lazopoulos, P Olgoso, J Santiago

- **Partial cross-checks** with arXiv:2108.03669 (on-shell amplitude methods). ✓
  and with arXiv:2307.03187 ✓ — Assi, Helset, Manohar, Pagès, Shen

arXiv:2108.03669
- M A Huber, S De Angelis.

Bosonic-bosonic RGE:

Classes of tree-generated bosonic operators

	$\phi^4 D^4$	$B\phi^4 D^2$	$W\phi^4 D^2$	$B^2\phi^4$	$W^2\phi^4$	$WB\phi^4$	$G^2\phi^4$	$\phi^6 D^2$	ϕ^8
$B^2\phi^2 D^2$	g_1^2	0	0	0	0	0	0	0	0
$W^2\phi^2 D^2$	g_2^2	0	0	0	0	0	0	0	0
$WB\phi^2 D^2$	$g_1 g_2$	0	0	0	0	0	0	0	0
$G^2\phi^2 D^2$	0	0	0	0	0	0	0	0	0
$W^3\phi^2$	0	0	0	0	0	0	0	0	0
$W^2 B\phi^2$	0	0	0	0	0	0	0	0	0
$G^3\phi^2$	0	0	0	0	0	0	0	0	0
$\phi^4 D^4$	g_2^2	0	0	0	0	0	0	0	0
$B\phi^4 D^2$	$g_1 g_2^2$	λ	0	0	0	0	0	0	0
$W\phi^4 D^2$	g_2^3	0	g_2^2	0	0	0	0	0	0
$B^2\phi^4$	$g_1^2 g_2^2$	$g_1\lambda$	$g_1^2 g_2$	λ	0	$g_1 g_2$	0	0	0
$W^2\phi^4$	g_2^4	$g_1 g_2^2$	g_2^3	0	λ	$g_1 g_2$	0	0	0
$WB\phi^4$	$g_1 g_2^3$	$g_2\lambda$	$g_1\lambda$	$g_1 g_2$	$g_1 g_2$	λ	0	0	0
$G^2\phi^4$	0	0	0	0	0	0	g_3^2	0	0
$\phi^6 D^2$	g_2^4	$g_1\lambda$	$g_2\lambda$	0	0	0	0	λ	0
ϕ^8	λ^3	$g_1\lambda^2$	$g_2\lambda^2$	$g_1^2\lambda$	$g_2^2\lambda$	$g_1 g_2\lambda$	0	λ^2	λ

- **Largest contribution from each operator class is shown.**
- **Loop generated operators that are renormalized by tree-generated operators are in gray.**
- **Blue entries contribute larger than what expected from naive dimensional analysis.**

$$\tilde{\mu}\frac{dc_{\phi^8}}{d\tilde{\mu}} = \frac{1}{16\pi^2}\left(192\lambda - 6(g_1^2 + 3g_2^2) + \dots\right) c_{\phi^8}$$

Fermionic-bosonic RGE:

Classes of tree-generated fermionic operators

	$\psi^2B\phi^3$	$\psi^2W\phi^3$	$\psi^2G\phi^3$	$\psi^2\phi^2D^3$	$\psi^2\phi^5$	$\psi^2\phi^4D$	$\psi^2B\phi^2D$	$\psi^2W\phi^2D$	$\psi^2G\phi^2D$	$\psi^2\phi^3D^2$
$B^2\phi^2D^2$	0	0	0	g_1^2	0	0	0	0	0	0
$W^2\phi^2D^2$	0	0	0	g_2^2	0	0	0	0	0	0
$WB\phi^2D^2$	0	0	0	g_1g_2	0	0	0	0	0	0
$G^2\phi^2D^2$	0	0	0	g_3^2	0	0	0	0	0	0
$W^3\phi^2$	0	0	0	0	0	0	0	0	0	0
$W^2B\phi^2$	0	0	0	0	0	0	0	0	0	0
$G^3\phi^2$	0	0	0	0	0	0	0	0	0	0
ϕ^4D^4	0	0	0	$\|y^t\|^2$	0	0	0	0	0	0
$B\phi^4D^2$	0	0	0	$g_1\|y^t\|^2$	0	0	$\|y^t\|^2$	0	0	g_1y^t
$W\phi^4D^2$	0	0	0	$g_2\|y^t\|^2$	0	0	0	$\|y^t\|^2$	0	g_2y^t
$B^2\phi^4$	g_1y^t	0	0	$g_1^2\|y^t\|^2$	0	0	$g_1\|y^t\|^2$	0	0	$g_1^2y^t$
$W^2\phi^4$	0	g_2y^t	0	$g_2^2\|y^t\|^2$	0	g_2^2	0	$g_2\|y^t\|^2$	0	$g_2^2y^t$
$WB\phi^4$	g_2y^t	g_1y^t	0	$g_1g_2\|y^t\|^2$	0	g_1g_2	$g_2\|y^t\|^2$	$g_1\|y^t\|^2$	0	$g_1g_2y^t$
$G^2\phi^4$	0	0	g_3y^t	0	0	0	0	0	0	0
ϕ^6D^2	0	0	0	$g_2^2\|y^t\|^2$	0	$\|y^t\|^2$	$g_1\|y^t\|^2$	$g_2\|y^t\|^2$	0	$y^t\|y^t\|^2$
ϕ^8	0	0	0	$\lambda\|y^t\|^4$	$y^t\|y^t\|^2$	$\lambda\|y^t\|^2$	$g_1\lambda\|y^t\|^2$	$g_2\lambda\|y^t\|^2$	0	$\lambda y^t\|y^t\|^2$

$$\dot{c}^{(1)}_{W\phi^4D^2} = 44g_2(c^{(4)}_{q^2\phi^2D^3})_{\alpha_1,\alpha_2}\, y^u_{\alpha_2,\alpha_3}(y^u)^*_{\alpha_3,\alpha_1} + 48(c^{(11)}_{q^2WH^2D})_{\alpha_1,\alpha_2}\, y^u_{\alpha_2,\alpha_3}(y^u)^*_{\alpha_1,\alpha_3} + \cdots$$

RGEs of Dim-6,4,2

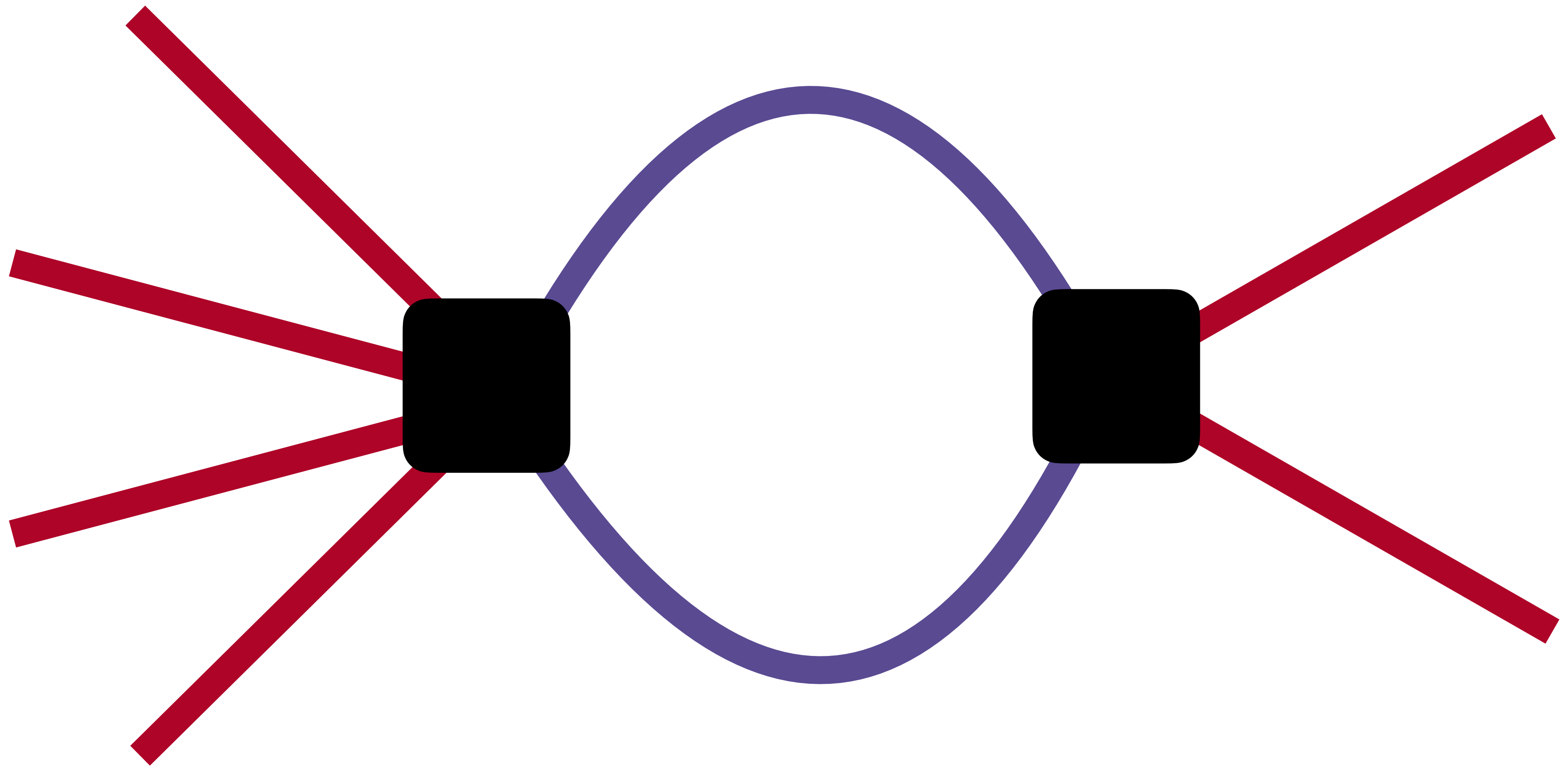
- Dim-8 operators also induce running of dim-6, dim-4, dim-2 operators.

μ^2 is the squared Higgs mass in the SMEFT.

	$\phi^4 D^4$	$B\phi^4 D^2$	$W\phi^4 D^2$	$B^2\phi^4$	$W^2\phi^4$	$WB\phi^4$	$G^2\phi^4$	$\phi^6 D^2$	ϕ^8
ϕ^2	μ^6	0	0	0	0	0	0	0	0
ϕ^4	$\lambda\mu^4$	$g_1\mu^4$	$g_2\mu^4$	0	0	0	0	μ^4	0
$B^2\phi^2$	$g_1^2\mu^2$	$g_1\mu^2$	0	μ^2	0	0	0	0	0
$W^2\phi^2$	$g_2^2\mu^2$	0	$g_2\mu^2$	0	μ^2	0	0	0	0
$WB\phi^2$	$g_1 g_2\mu^2$	$g_2\mu^2$	$g_1\mu^2$	0	0	μ^2	0	0	0
$G^2\phi^2$	0	0	0	0	0	0	μ^2	0	0
$\phi^4 D^2$	$\lambda\mu^2$	$g_1\mu^2$	$g_2\mu^2$	0	0	0	0	μ^2	0
ϕ^6	$\lambda^2\mu^2$	$\lambda g_1\mu^2$	$\lambda g_2\mu^2$	$g_1^2\mu^2$	$g_2^2\mu^2$	$g_1 g_2\mu^2$	0	$\lambda\mu^2$	μ^2

$\times 1/\Lambda^4$

Lower dim. classes renormalized by the bosonic dim-8 operators.
Similar contributions from two-fermionic dim-8 operators are also present.



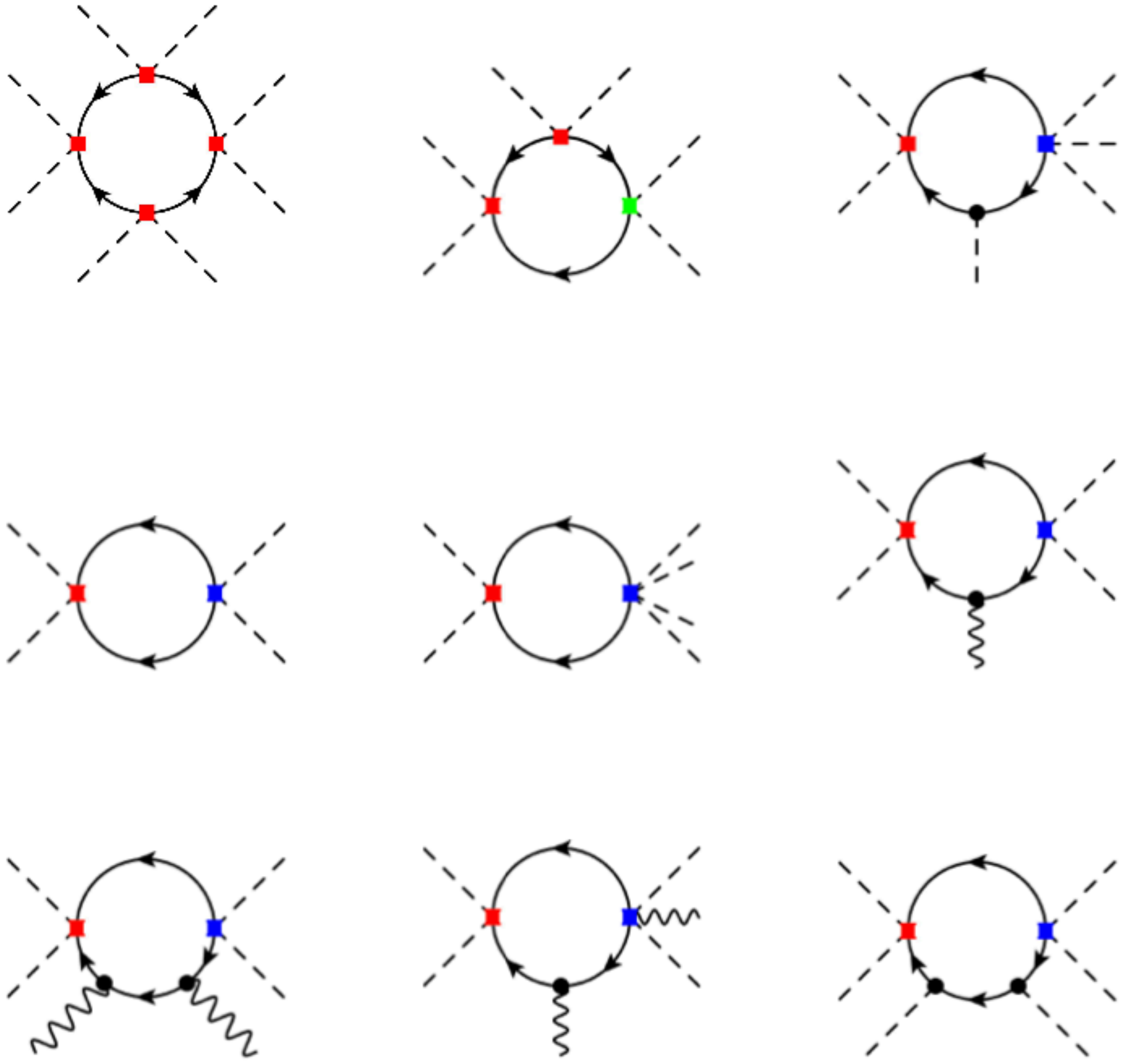
Part 2 : Dim-8 renormalization by Dim-5 & Dim-7

arXiv:2301.07151

LNV contributions (1-loop) to bosonic SMEFT: D5, D6, D7 insertions

$1/\Lambda^4$	d_5^4	$d_5^2 \times d_6$	$d_5 \times d_7$
8-Higgs	✓	-	-
6-Higgs	-	✓	✓
4-Higgs	-	-	✓
2-Higgs	-	-	-
0-Higgs	-	-	-

The hyphen stands for the vanishing contributions from LNVs upto Λ^{-3} at 1-loop.



Bosonic SMEFT RGEs from LNVs :

	$(\alpha_{\ell\phi})^4$	$(\alpha_{\ell\phi})^2\,\beta_{\phi D}$	$(\alpha_{\ell\phi})^2\,\beta^{(1)}_{\phi\ell}$	$(\alpha_{\ell\phi})^2\,\beta^{(3)}_{\phi\ell}$	$\alpha_{\ell\phi}\omega_{\ell\phi}$	$\alpha_{\ell\phi}\omega^{(1)}_{\ell\phi D}$	$\alpha_{\ell\phi}\omega^{(2)}_{\ell\phi D}$	$\alpha_{\ell\phi}\omega_{\ell\phi De}$	$\alpha_{\ell\phi}\omega_{\ell\phi W}$
γ_{ϕ^8}	16	8λ	32λ	32λ	16λ	$2\lambda g_2^2$	λg_2^2	0	0
$\gamma^{(1)}_{\phi^6}$	0	4	48	64	16	$\frac{14}{3}g_2^2$	32λ	$4y^e$	0
$\gamma^{(2)}_{\phi^6}$	0	8	32	16	8	$\frac{1}{6}g_2^2$	16λ	$4y^e$	0
$\gamma^{(2)}_{\phi^4}$	0	0	0	0	0	$\emptyset$	8	0	0
$\gamma^{(1)}_{W\phi^4D^2}$	0	0	0	0	0	$8g_2$	$4g_2$	0	$\emptyset$
$\gamma^{(2)}_{W\phi^4D^2}$	0	0	0	0	0	$8g_2$	$4g_2$	0	$\emptyset$
$\gamma^{(3)}_{W\phi^4D^2}$	0	0	0	0	0	$4g_2$	$2g_2$	0	$\emptyset$
$\gamma^{(4)}_{W\phi^4D^2}$	0	0	0	0	0	$4g_2$	$2g_2$	0	$\emptyset$
$\gamma^{(1)}_{W^2\phi^4}$	0	0	0	0	0	$\frac{1}{2}g_2^2$	$\frac{1}{4}g_2^2$	0	$4g_2$
$\gamma^{(2)}_{W^2\phi^4}$	0	0	0	0	0	$\frac{1}{2}g_2^2$	$\frac{1}{4}g_2^2$	0	$4g_2$
$\gamma^{(3)}_{W^2\phi^4}$	0	0	0	0	0	$\frac{1}{2}g_2^2$	$\frac{1}{4}g_2^2$	0	$4g_2$
$\gamma^{(4)}_{W^2\phi^4}$	0	0	0	0	0	$\frac{1}{2}g_2^2$	$\frac{1}{4}g_2^2$	0	$4g_2$
$\gamma^{(1)}_{WB\phi^4}$	0	0	0	0	0	g_1g_2	$\frac{1}{2}g_1g_2$	0	$\emptyset$
$\gamma^{(2)}_{WB\phi^4}$	0	0	0	0	0	g_1g_2	$\frac{1}{2}g_1g_2$	0	$\emptyset$
γ_{ϕ}	0	$4\mu^2$	$16\mu^2$	$16\mu^2$	$8\mu^2$	$\mu^2g_2^2$	$16\mu^2\lambda$	0	0
$\gamma_{\phi\Box}$	0	0	0	0	0	0	$16\mu^2$	0	0
$\gamma_{\phi D}$	0	0	0	0	0	0	$16\mu^2$	0	0
γ_{λ}	0	0	0	0	0	0	$8\mu^4$	0	0

Simple Application (in context of LNVs) :

$$T = -\frac{1}{2\alpha}\frac{v^2}{\Lambda^2}\left(c_{\phi D} + c_{\phi 6}^{(2)}\frac{v^2}{\Lambda^2}\right) \qquad \alpha = \frac{1}{137}$$

Blas et. al. 2017
arxiv:1611.05354

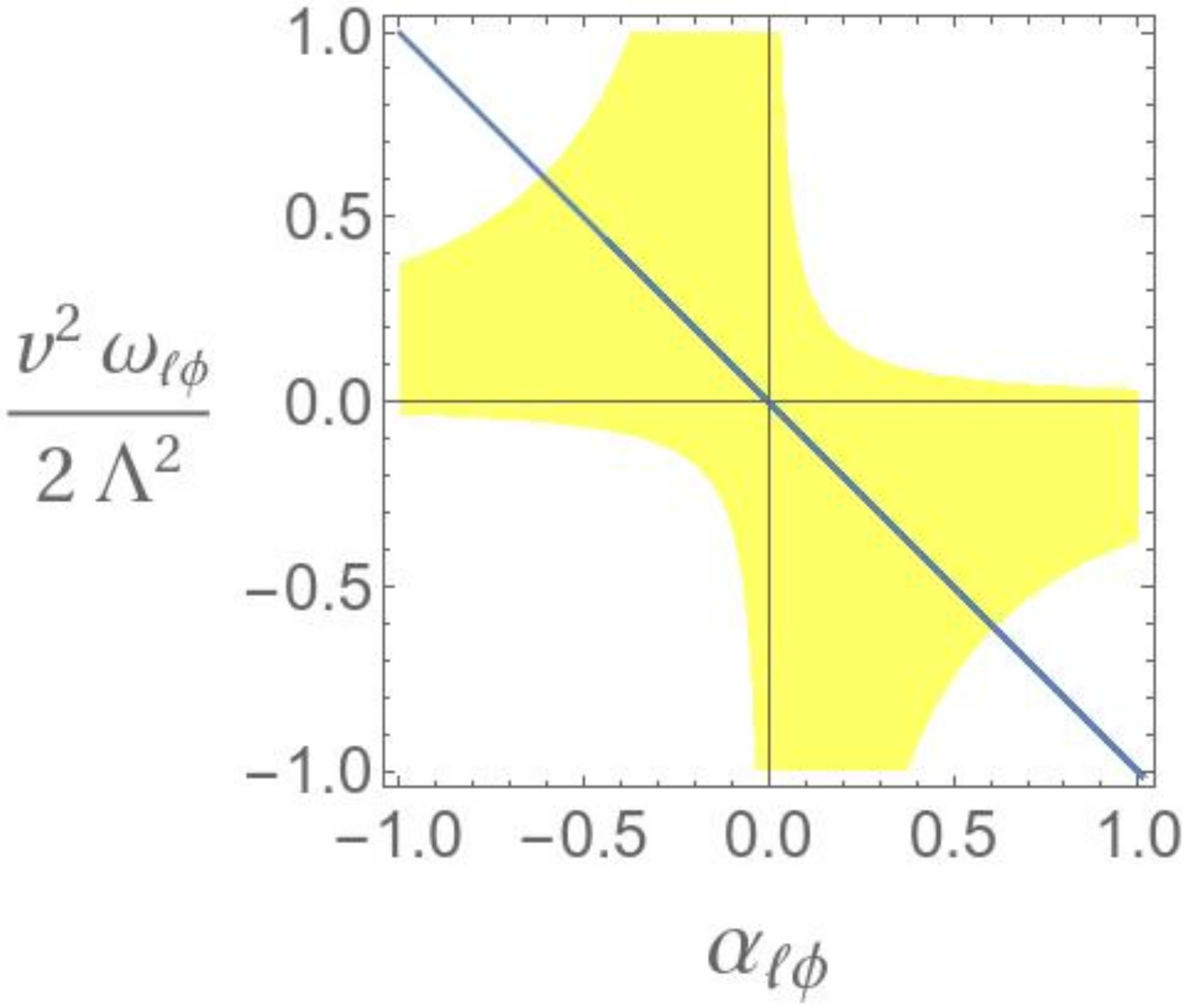
$$\dot{c}_{\phi 6}^{(2)} \supset -8\,\mathrm{Re}\left(\mathrm{Tr}\left[\alpha_{\ell\phi}^{\dagger}\omega_{\ell\phi}\right]\right)$$

$$\therefore \qquad T = -\frac{1}{4\pi^2\alpha}\frac{v^4}{\Lambda^4}\ln\left[\frac{\Lambda}{\mu}\right]\sum_{mn}^{3}\alpha_{\ell\phi,mn}\omega_{\ell\phi,mn}$$

Simple Application :

Neutrino mass bounds: $$(M_N)_{mn} = -\frac{v^2}{\Lambda}\left(\alpha_{\ell\phi,mn} + \frac{v^2}{2\Lambda^2}\omega_{\ell\phi,mn}\right)$$

For single non-vanishing flavor direction :



$$\alpha_{\ell\phi} \to \epsilon_{ij}\epsilon_{mn}(\ell^i C\ell^m)(\phi^j\phi^n)$$

$$\omega_{\ell\phi} \to \epsilon_{ij}\epsilon_{mn}(\ell^i C\ell^m)(\phi^j\phi^n)(\phi^\dagger\phi)$$

$\Lambda = 1$ TeV, and $\mu = 246$ GeV,
$T = 0.10 \pm 0.12$, and $M_N < 0.081$ eV

Blas et. al. 2017
arxiv:1611.05354

Loureiro et. al. 2018
arxiv:1811.02578

Summary

- **Renormalization of bosonic SMEFT dim-8 operators discussed.**
  - **By Tree-level generated dim-8 operators.**
  - **By dim-5 & dim-7 LNV operators.**
- **These operators also contribute to the running of lower dimensional operators.**
- **Certain elements contribute larger than what expected from naive dimensional analysis.**
- **T-parameter example: RGEs translate bounds to blind direction of LNV spaces.**

Thanks!