Understanding the quantum structure of the dimension-8 SMEFT

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based on *2106.05291*, *2110.01264*, *2301.09995* *and ongoing work*

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The SMEFT is the SM extended with effective operators

(Probably) the most reasonable model of new physics

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4}\mathcal{O}_j^{(8)} + \cdots$$

If probed by experiments at very different scales, RGEs of the theory are needed [Jenkins, Manohar, Trott, Alonso '13].

Interesting theoretical aspects at dimension 8 (positivity, tree-loop mixing, test tools, ...)

Besides pure theoretical considerations, anomalous dimensions of dimension-8 operators [Murphy '20; Li, Ren, Shu, Xiao, Yu, Zheng '20] not always phenomenologically irrelevant

Simplest example:

Custodial symmetry violation absent at tree-level dimension-6, one-loop dimension-6 and tree-level dimension-8 [**MC**, Krause, Nardini '18; Durieux, McCullough, Salvioni '22]

Some partial results:

MC, Guedes, Ramos, Santiago; 2106.05291
Accettulli Huber, De Angelis; 2108.03669
Bakshi, **MC**, Diaz-Carmona, Guedes; 2205.03301
Helset, Jenkins, Manohar; 2212.03253
Asteriadis, Dawson, Fontes; 2212.03258
Bakshi, Diaz-Carmona; 2301.07151

More generally, certain aspects of the full anomalous dimension matrix well understood

Craig, Jiang, Li, Sutherland; 2001.00017

$\overline{w}$ \ w	0	2	4	6	8
8	X_L^4	$X_L^3 H^2$, $X_L^2 \psi^2 H$, $X_L \psi^4$	$X_L^2 H^4$, $X_L \psi^2 H^3$, $\psi^4 H^2$	$\psi^2 H^5$	H^8
6		$X_L^2 H^2 D^2$, $X_L^2 \psi \bar{\psi} D$, $X_L \psi^2 H D^2$, $\psi^4 D^2$	$X_L H^4 D^2$, $X_L^2 \bar{\psi}^2 H$, $X_L \psi \bar{\psi} H^2 D$, $\psi^2 H^3 D^2$, $X_L \psi^2 \bar{\psi}^2$, $\psi^3 \bar{\psi} H D$	$H^6 D^2$, $\psi \bar{\psi} H^4 D$, $\psi^2 \bar{\psi}^2 H^2$	$\bar{\psi}^2 H^5$
4			$X_L^2 X_R^2$, $X_L X_R H^2 D^2$, $H^4 D^4$, $X_L X_R \psi \bar{\psi} D$, $X_R \psi^2 H D^2$, $X_L \bar{\psi}^2 H D^2$, $\psi \bar{\psi} H^2 D^3$, $\psi^2 \bar{\psi}^2 D^2$	$X_R H^4 D^2$, $X_R^2 \psi^2 H$, $X_R \psi \bar{\psi} H^2 D$, $\bar{\psi}^2 H^3 D^2$, $X_R \psi^2 \bar{\psi}^2$, $\psi \bar{\psi}^3 H D$	$X_R^2 H^4$, $X_R \bar{\psi}^2 H^3$, $\bar{\psi}^4 H^2$
2				$X_R^2 H^2 D^2$, $X_R^2 \psi \bar{\psi} D$, $X_R \bar{\psi}^2 H D^2$, $\bar{\psi}^4 D^2$	$X_R^3 H^2$, $X_R^2 \bar{\psi}^2 H$, $X_R \bar{\psi}^4$
0					X_R^4

Murphy ‘20;
based on Craig et al ‘20

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6		$X_L^2H^2D^2$, $X_L^2\psi\bar{\psi}D$, $X_L\psi^2HD^2$, ψ^4D^2	$X_LH^4D^2$, $X_L^2\bar{\psi}^2H$, $X_L\psi\bar{\psi}H^2D$, $\psi^2H^3D^2$, $X_L\psi^2\bar{\psi}^2$, $\psi^3\bar{\psi}HD$	H^6D^2, $\psi\bar{\psi}H^4D$, $\psi^2\bar{\psi}^2H^2$	$\bar{\psi}^2H^5$
4			$X_L^2X_R^2$, $X_LX_RH^2D^2$, H^4D^4, $X_LX_R\psi\bar{\psi}D$, $X_R\psi^2HD^2$, $X_L\bar{\psi}^2HD^2$, $\psi\bar{\psi}H^2D^3$, $\psi^2\bar{\psi}^2D^2$	$X_RH^4D^2$, $X_R^2\psi^2H$, $X_R\psi\bar{\psi}H^2D$, $\bar{\psi}^2H^3D^2$, $X_R\psi^2\bar{\psi}^2$, $\psi\bar{\psi}^3HD$	$X_R^2H^4$, $X_R\bar{\psi}^2H^3$, $\bar{\psi}^4H^2$
2				$X_R^2H^2D^2$, $X_R^2\psi\bar{\psi}D$, $X_R\bar{\psi}^2HD^2$, $\bar{\psi}^4D^2$	$X_R^3H^2$, $X_R^2\bar{\psi}^2H$, $X_R\bar{\psi}^4$
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4			$X_L^2X_R^2$, $X_LX_RH^2D^2$, H^4D^4, $X_LX_R\psi\bar{\psi}D$, $X_R\psi^2HD^2$, $X_L\bar{\psi}^2HD^2$, $\psi\bar{\psi}H^2D^3$, $\psi^2\bar{\psi}^2D^2$	$X_RH^4D^2$, $X_R^2\psi^2H$, $X_R\psi\bar{\psi}H^2D$, $\bar{\psi}^2H^3D^2$, $X_R\psi^2\bar{\psi}^2$, $\psi\bar{\psi}^3HD$	$X_R^2H^4$, $X_R\bar{\psi}^2H^3$, $\bar{\psi}^4H^2$
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0					X_R^4

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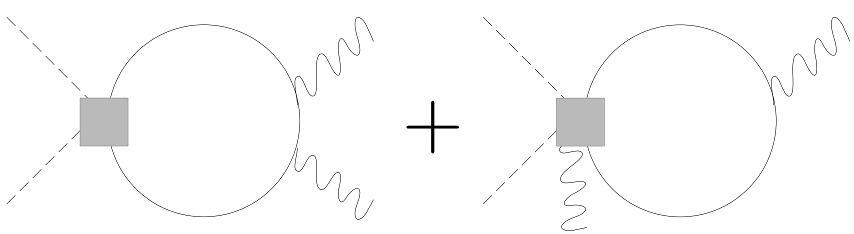
It is obvious that there are zeros in mixing of specific operators of different classes

It is not so clear how to anticipate them, not even with amplitude methods

$$\mathcal{O}^{(1)}_{e^2\phi^2 D^3} = i(\bar{e}\gamma^\mu D^\nu e)(D_{(\mu}D_{\nu)}\phi^\dagger\phi) + \text{h.c.}$$

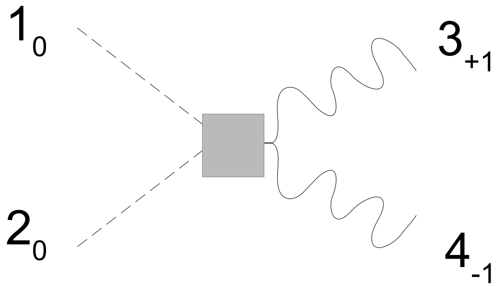
$$\mathcal{O}^{(1)}_{B^2\phi^2 D^2} = (D^\mu\phi^\dagger D^\nu\phi)B_{\mu\rho}B^\rho_\nu$$

$$\mathcal{O}^{(2)}_{e^2\phi^2 D^3} = i(\bar{e}\gamma^\mu D^\nu e)(\phi^\dagger D_{(\mu}D_{\nu)}\phi) + \text{h.c.}$$

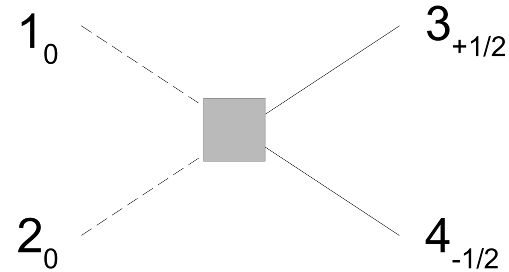


$$+\cdots$$

$$\underbrace{\mathcal{O}^{(1)}_{e^2\phi^2 D^3} - \mathcal{O}^{(2)}_{e^2\phi^2 D^3}}_{\widetilde{\mathcal{O}}^{(1)}_{e^2\phi^2 D^3}} \not\rightarrow \mathcal{O}^{(1)}_{B^2\phi^2 D^2}$$

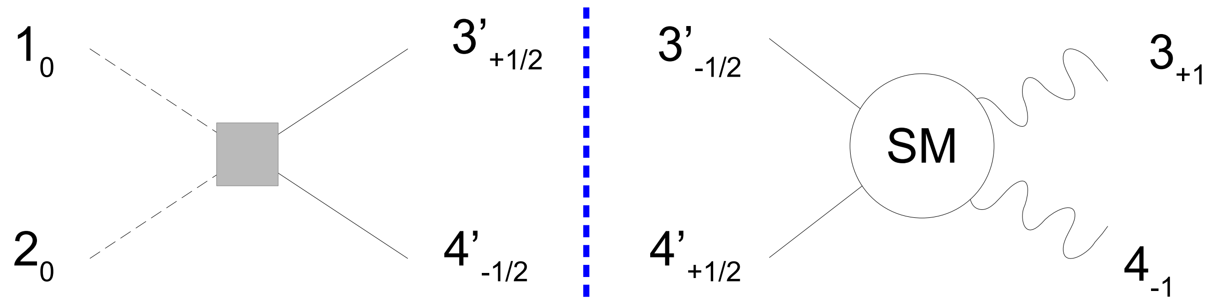


$$= \langle 41\rangle^2 [31]^2$$



$$= \langle 43\rangle\langle 41\rangle [43][31]$$

$$\gamma_{\tilde{c}^{(1)}_{e^2\phi^2 D^3} \to c^{(1)}_{B^2\phi^2 D^2}} \propto$$

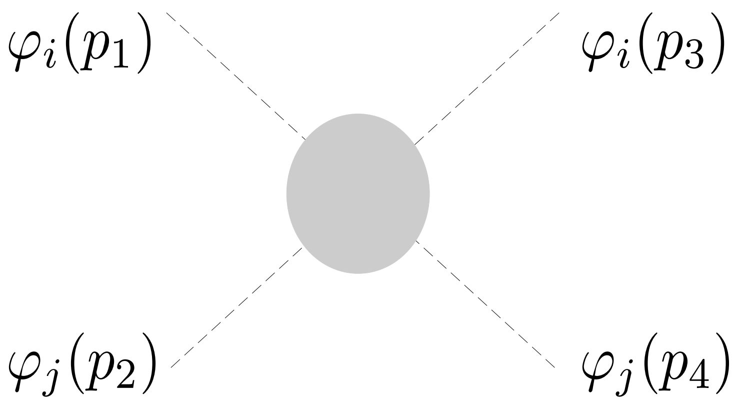


$$= \int d\mathrm{LIPS} \langle 4'3'\rangle\langle 4'1\rangle [4'3'][3'1] \frac{\langle 3'4\rangle^2}{\langle 3'3\rangle\langle 34'\rangle}$$

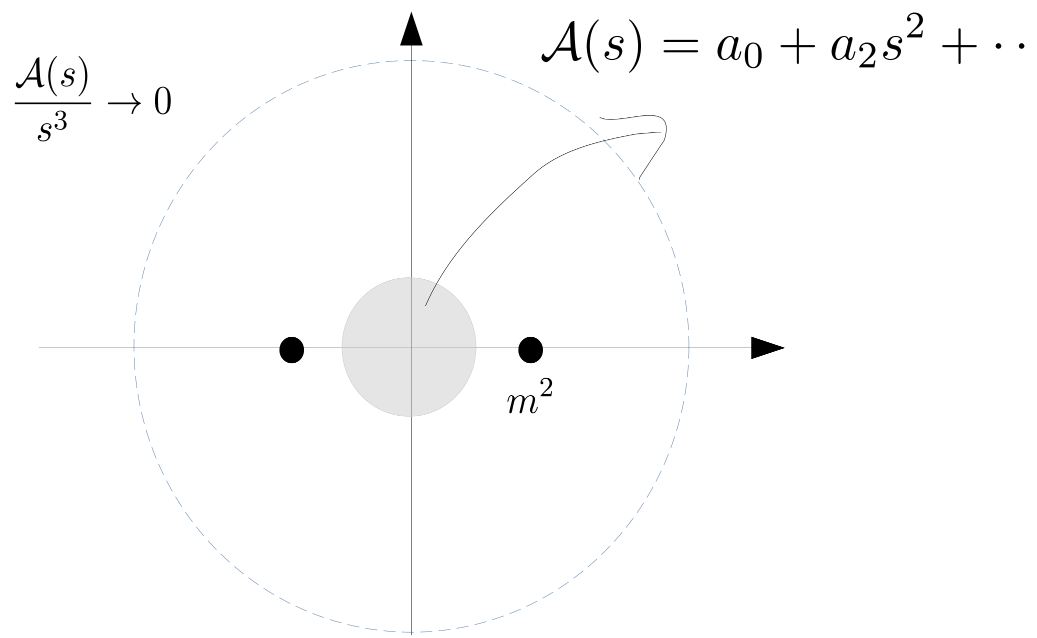
$$= \int_0^{2\pi} d\phi \int_0^{\pi/2} d\theta\, s_\theta c_\theta \left[\#_1 e^{i\phi} + \#_2 e^{2i\phi} + \cdots \right]$$

0

A different perspective: certain operators are constrained by positivity, from unitarity+locality [Adams, Arkani-Hamed, Nicolis, Rattazzi '06]



$$\mathcal{A}(s) \equiv \mathcal{A}(s, t=0)$$



$$0 = \sum \text{res} \frac{\mathcal{A}(s)}{s^3} = a_2 - \frac{1}{\pi} \int s \frac{\sigma(s)}{(m^2)^3} \Rightarrow a_2 > 0$$

A different perspective: certain operators are constrained by positivity, from unitarity+locality [Adams, Arkani-Hamed, Nicolis, Rattazzi '06]

$$c^{(1)}_{B^2\phi^2D^2} \leq 0$$

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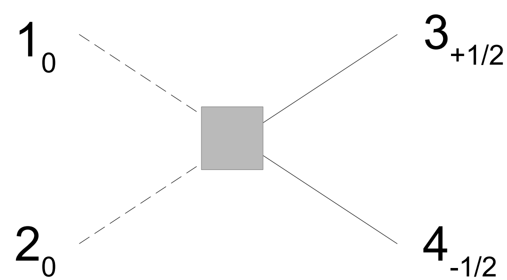
But some others are not:

$$\widetilde{\mathcal{O}}^{(1)}_{e^2\phi^2 D^3} =$$



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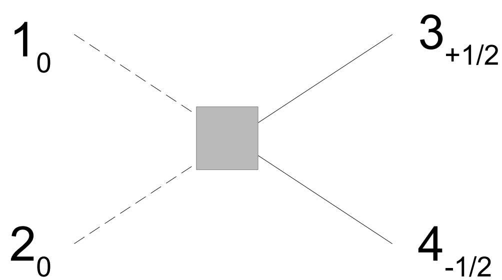
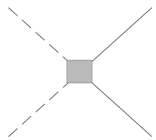
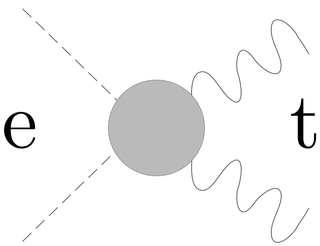
$$\widetilde{\mathcal{O}}^{(1)}_{e^2\phi^2 D^3} =$$ 

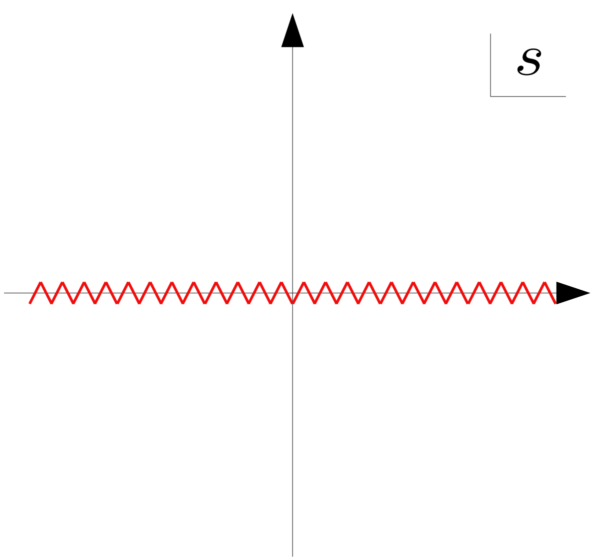
$$= \langle 43\rangle\langle 41\rangle[43][31]$$

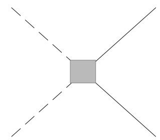
"Therefore",

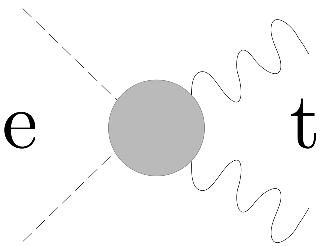
$$\dot{c}^{(1)}_{B^2\phi^2 D^2} = \#_1 \tilde{c}^{(1)}_{e^2\phi^2 D^3} + \cdots \Rightarrow \#_1 = 0$$

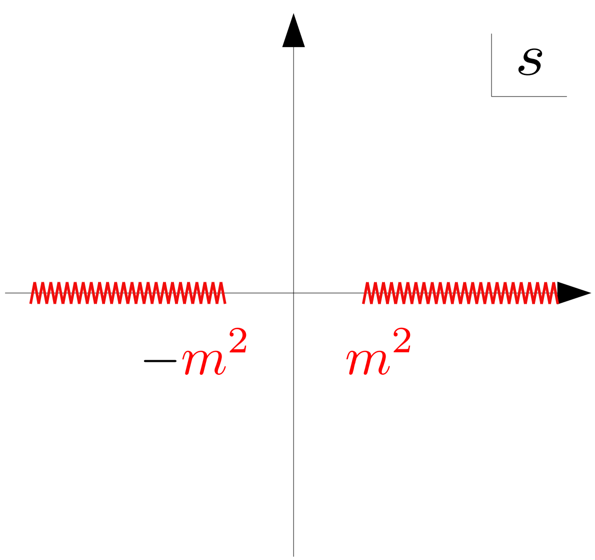
1. For any $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ (and lower-dimensional  ones) at tree level.

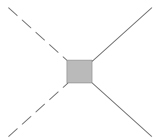
2. Within any such UV, compute  to order $O(g^2)$

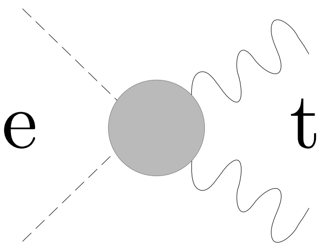


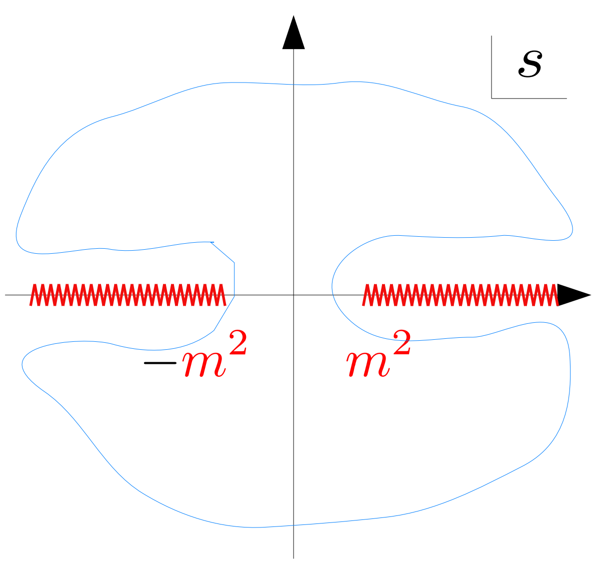
1. For any $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ (and lower-dimensional  ones) at tree level.

2. Within any such UV, compute  to order $O(g^2)$

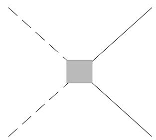


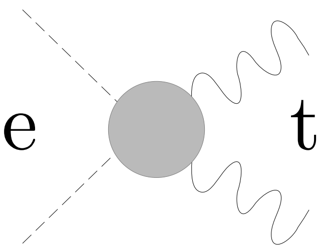
1. For any $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ (and lower-dimensional  ones) at tree level.

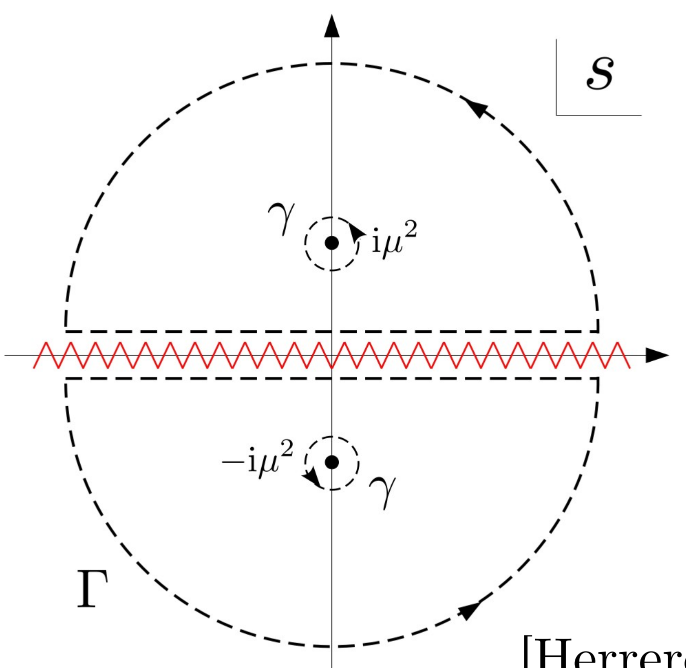
2. Within any such UV, compute  to order $O(g^2)$



See Minyuan's talk

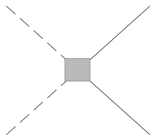
1. For any $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ (and lower-dimensional  ones) at tree level.

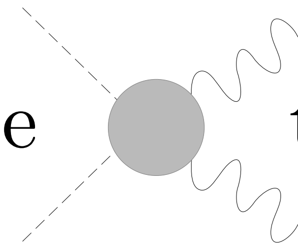
2. Within any such UV, compute  to order $O(g^2)$

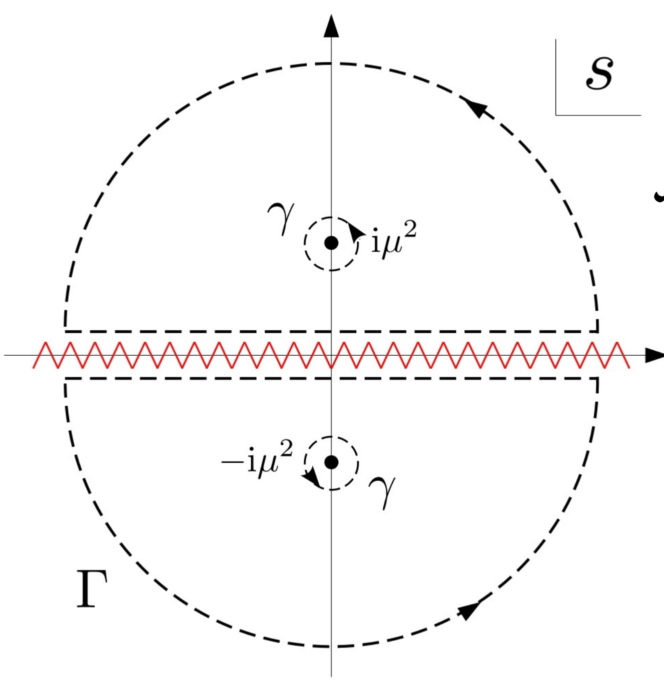


$$\Sigma(\mu) \equiv \frac{1}{2\pi \mathrm{i}} \int_\gamma \frac{\mathcal{A}(s) s^3}{(s^2+\mu^4)^3} \geq 0$$

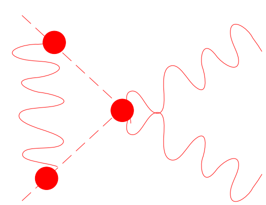
[Herrero-Valea et al ‘20]

1. For any $(c^{(1)}_{e^2\phi^2D^3}, c^{(2)}_{e^2\phi^2D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2D^3} + c^{(2)}_{e^2\phi^2D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2D^3}, c^{(2)}_{e^2\phi^2D^3})$ (and lower-dimensional  ones) at tree level.

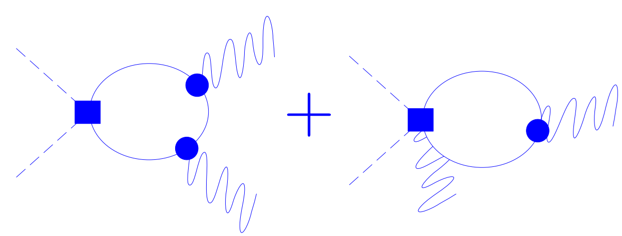
2. Within any such UV, compute  to order $O(g^2)$



$$\mathcal{A}(s) \sim -(\beta_4 + \beta_8 s^2 + \beta_{12} s^4 + \cdots) \log \frac{s}{\Lambda^2}$$



$+\cdots$



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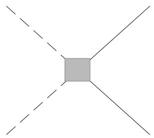
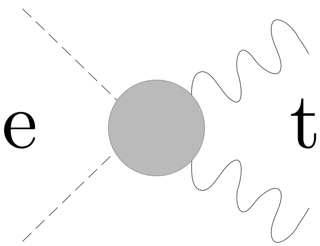
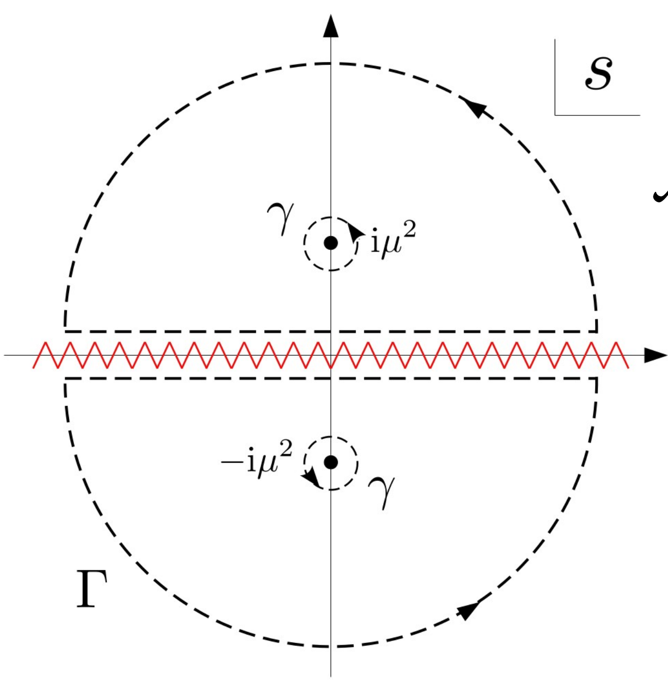
1. For any $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ (and lower-dimensional  ones) at tree level.

2. Within any such UV, compute  to order $\mathrm{O}(g^2)$



$$\mathcal{A}(s) \sim -(\beta_4 + \beta_8 s^2 + \beta_{12} s^4 + \cdots) \log \frac{s}{\Lambda^2}$$

$$\Sigma(\mu) = -\beta_8 + \beta_{12}\mu^4 + \cdots$$

$$\Rightarrow \lim_{\mu \to 0} \Sigma(\mu) = -\beta_8 \geq 0$$

So $\beta_8 \leq 0$ in any of the aforementioned UV, and therefore for all values of $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with $c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$

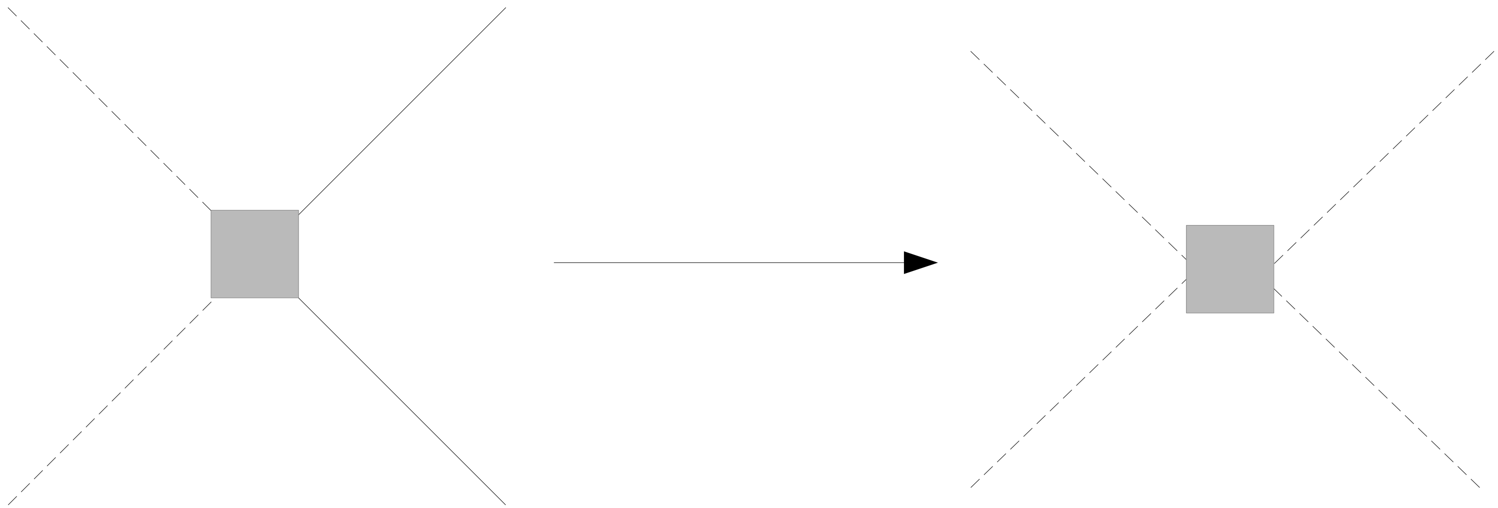
3. The beta function is linear in the Wilson coefficients:

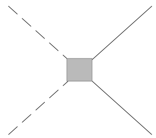
$$\beta_8 = \alpha(c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3}) \,, \quad \alpha \geq 0$$

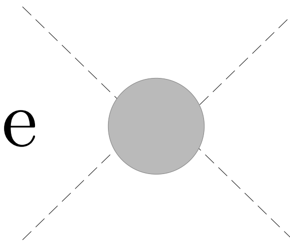
Therefore,

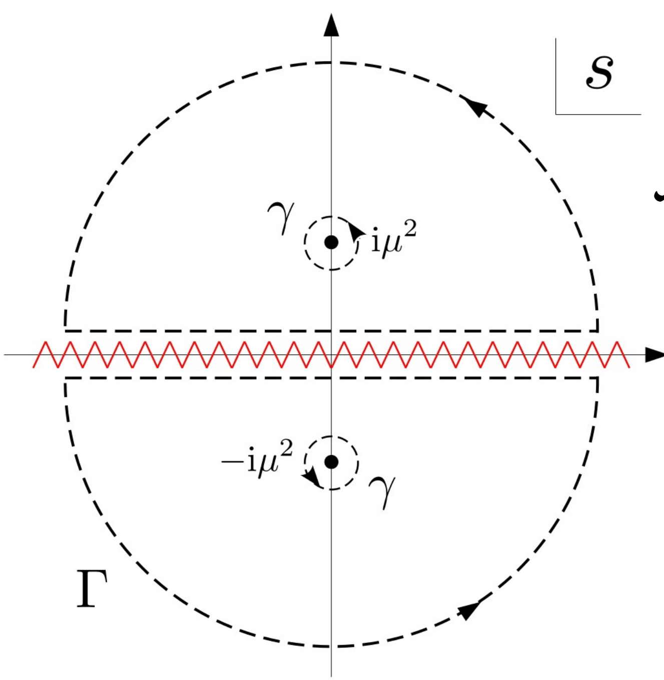
$$\underbrace{\mathcal{O}^{(1)}_{e^2\phi^2 D^3} - \mathcal{O}^{(2)}_{e^2\phi^2 D^3}}_{\widetilde{\mathcal{O}}^{(1)}_{e^2\phi^2 D^3}} \not\longrightarrow \mathcal{O}^{(1)}_{B^2\phi^2 D^2}$$

How do things change if we consider instead...?

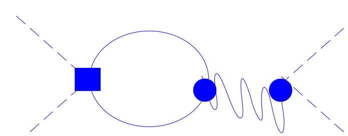


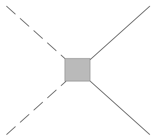
1. For any $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ (and lower-dimensional  ones) at tree level.

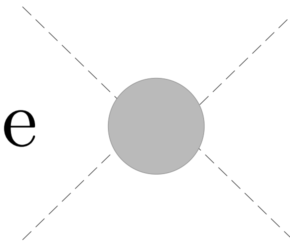
2. Within any such UV, compute  to order $\mathrm{O}(g^2)$

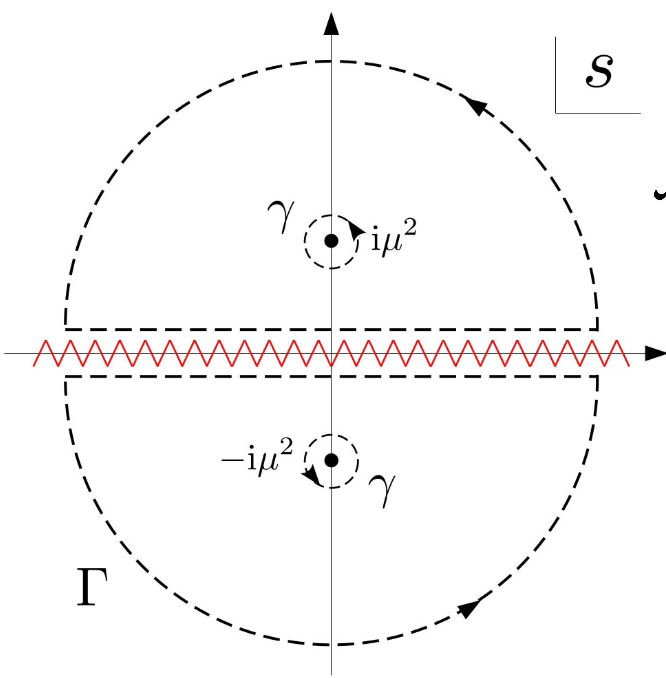


$$\mathcal{A}(s) \sim -(\beta_4 + \beta_8 s^2 + \beta_{12} s^4 + \cdots) \log \frac{s}{\Lambda^2}$$

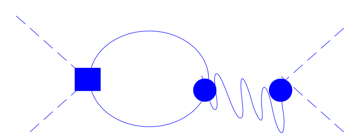
$\cdots$  $+ \cdots$

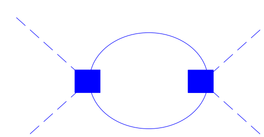
1. For any $(c^{(1)}_{e^2\phi^2D^3}, c^{(2)}_{e^2\phi^2D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2D^3} + c^{(2)}_{e^2\phi^2D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2D^3}, c^{(2)}_{e^2\phi^2D^3})$ (and lower-dimensional  ones) at tree level.

2. Within any such UV, compute  to order $O(g^2)$



$$\mathcal{A}(s) \sim -(\beta_4 + \beta_8 s^2 + \beta_{12} s^4 + \cdots) \log \frac{s}{\Lambda^2}$$

...  $+ \cdots$

$+$ 

The dim-6 squared contributions fulfill positivity:

$$c_{\phi^4}^{(2)} \geq 0\,, \quad c_{\phi^4}^{(1)} + c_{\phi^4}^{(2)} \geq 0\,, \quad c_{\phi^4}^{(1)} + c_{\phi^4}^{(2)} + c_{\phi^4}^{(3)} \geq 0$$

The dim-6 squared contributions fulfill positivity:

$$c^{(2)}_{\phi^4} \geq 0\,, \quad c^{(1)}_{\phi^4} + c^{(2)}_{\phi^4} \geq 0\,, \quad c^{(1)}_{\phi^4} + c^{(2)}_{\phi^4} + c^{(3)}_{\phi^4} \geq 0$$

$$16\pi^2 \beta^{(1)}_{H^4D^4} = \frac{8}{3}\Big[-2(c^{(1)}_{H^4D^2})^2 - \frac{11}{8}(c^{(2)}_{H^4D^2})^2 + 4c^{(1)}_{H^4D^2}c^{(2)}_{H^4D^2}$$
$$\underline{+3c^2_{Hd}}\ \underline{\underline{+c^2_{He}}}\ \underline{\underline{\underline{+2(c^{(1)}_{Hl})^2}}} - 2(c^{(3)}_{Hl})^2 \underline{\underline{\underline{\underline{+6(c^{(1)}_{Hq})^2}}}} - 6(c^{(3)}_{Hq})^2 + \underline{\underline{\underline{\underline{3c^2_{Hu}}}}} - 3c^2_{Hud}\Big]\,,$$

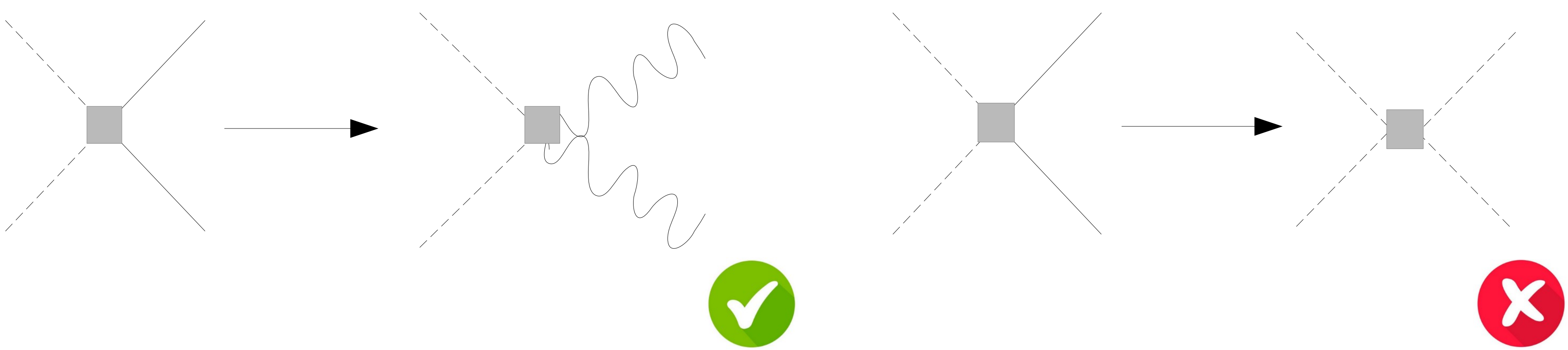
$$16\pi^2 \beta^{(2)}_{H^4D^4} = \frac{8}{3}\Big[-2(c^{(1)}_{H^4D^2})^2 - \frac{5}{8}(c^{(2)}_{H^4D^2})^2 - 2c^{(1)}_{H^4D^2}c^{(2)}_{H^4D^2}$$
$$\underline{-3c^2_{Hd}}\ \underline{\underline{-c^2_{He}}}\ \underline{\underline{\underline{-2(c^{(1)}_{Hl})^2}}} - 2(c^{(3)}_{Hl})^2 \underline{\underline{\underline{\underline{-6(c^{(1)}_{Hq})^2}}}} - 6(c^{(3)}_{Hq})^2 \underline{\underline{\underline{\underline{-3c^2_{Hu}}}}}\Big]\,,$$

$$16\pi^2 \beta^{(3)}_{H^4D^4} = \frac{8}{3}\Big[-5(c^{(1)}_{H^4D^2})^2 + \frac{7}{8}(c^{(2)}_{H^4D^2})^2 - 2c^{(1)}_{H^4D^2}c^{(2)}_{H^4D^2} + 4(c^{(3)}_{Hl})^2 + 12(c^{(3)}_{Hq})^2 + 3c^2_{Hud}\Big]$$

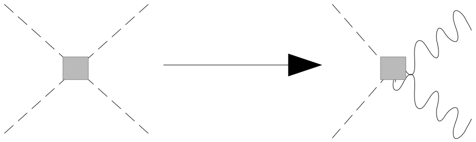
Resorting to the UV to understand the IR is only a trick. In general:

(1) Some tree-level O_i obey $c_i \geq 0$

(2) If O_i involves fields not present in O_j and c_j not constrained by positivity, then $\gamma_{ij} = 0$



Other aspects of anomalous dimensions: signs and inequalities

Let us consider the mixing 

Positivity bounds:

$$c_{\phi^4}^{(2)} \geq 0\,, \quad c_{\phi^4}^{(1)} + c_{\phi^4}^{(2)} \geq 0\,, \quad c_{\phi^4}^{(1)} + c_{\phi^4}^{(2)} + c_{\phi^4}^{(3)} \geq 0$$

$$\dot{c}_{B^2\phi^2D^2}^{(1)} \geq 0$$

From where we obtain:

$$\begin{aligned}\dot{c}_{B^2\phi^2D^2}^{(1)} &= \alpha(c_{\phi^4}^{(1)} + c_{\phi^4}^{(2)} + c_{\phi^4}^{(3)}) + \beta(c_{\phi^4}^{(1)} + c_{\phi^4}^{(2)}) + \gamma c_{\phi^4}^{(2)} + \cdots \\ &= (\alpha+\beta)c_{\phi^4}^{(1)} + (\alpha+\beta+\gamma)c_{\phi^4}^{(2)} + \alpha c_{\phi^4}^{(3)} + \cdots\,,\end{aligned}$$

Other aspects of anomalous dimensions: signs and inequalities

$$\dot{c}^{(1)}_{B^2\phi^2 D^2} = \alpha(c^{(1)}_{\phi^4} + c^{(2)}_{\phi^4} + c^{(3)}_{\phi^4}) + \beta(c^{(1)}_{\phi^4} + c^{(2)}_{\phi^4}) + \gamma c^{(2)}_{\phi^4} + \cdots$$
$$= (\alpha+\beta) c^{(1)}_{\phi^4} + (\alpha+\beta+\gamma) c^{(2)}_{\phi^4} + \alpha c^{(3)}_{\phi^4} + \cdots\,,$$

1. The anomalous dimensions are positive

	$c^{(1)}_{\phi^4 D^4}$	$c^{(2)}_{\phi^4 D^4}$	$c^{(3)}_{\phi^4 D^4}$
$c^{(1)}_{B^2\phi^2 D^2}$	+	+	+

2. They fulfill

$$\gamma_{c^{(1)}_{B^2\phi^2 D^2},\, c^{(2)}_{\phi^4 D^4}} \geq \gamma_{c^{(1)}_{B^2\phi^2 D^2},\, c^{(1)}_{\phi^4 D^4}} \geq \gamma_{c^{(1)}_{B^2\phi^2 D^2},\, c^{(3)}_{\phi^4 D^4}}$$

Full electroweak SMEFT (with no flavour)

	$c^{(1)}_{\phi^4 D^4}$	$c^{(2)}_{\phi^4 D^4}$	$c^{(3)}_{\phi^4 D^4}$	$\tilde{c}^{(1)}_{e^2\phi^2 D^3}$	$\tilde{c}^{(2)}_{e^2\phi^2 D^3}$	$\tilde{c}^{(1)}_{l^2\phi^2 D^3}$	$\tilde{c}^{(2)}_{l^2\phi^2 D^3}$	$\tilde{c}^{(3)}_{l^2\phi^2 D^3}$	$\tilde{c}^{(4)}_{l^2\phi^2 D^3}$	$c_{e^4 D^2}$	$c^{(1)}_{l^4 D^2}$	$c^{(2)}_{l^4 D^2}$	$c^{(1)}_{l^2 e^2 D^2}$	$c^{(2)}_{l^2 e^2 D^2}$
$c^{(1)}_{B^2\phi^2 D^2}$	+	+	+	$\boxed{0}$	−	$\boxed{0}$	−	$\boxed{0}$	−	0	0	0	0	0
$c^{(1)}_{W^2\phi^2 D^2}$	+	+	+	0	0	$\boxed{0}$	−	$\boxed{0}$	−	0	0	0	0	0
$\tilde{c}^{(2)}_{e^2\phi^2 D^3}$	+	+	+	×	×	$\boxed{0}$	−	$\boxed{0}$	−	−	0	0	$\boxed{0}$	−
$\tilde{c}^{(2)}_{l^2\phi^2 D^3}$	+	+	+	$\boxed{0}$	−	×	×	×	×	0	−	−	$\boxed{0}$	−
$\tilde{c}^{(4)}_{l^2\phi^2 D^3}$	+	+	+	$\boxed{0}$	−	×	×	×	×	0	−	−	$\boxed{0}$	−
$c_{e^2 B^2 D}$	0	0	0	$\boxed{0}$	−	0	0	0	0	−	0	0	$\boxed{0}$	−
$c_{l^2 B^2 D}$	0	0	0	0	0	$\boxed{0}$	−	$\boxed{0}$	−	0	−	−	$\boxed{0}$	−
$c_{e^2 W^2 D}$	0	0	0	$\boxed{0}$	−	0	0	0	0	0	0	0	$\boxed{0}$	−
$c^{(1)}_{l^2 W^2 D}$	0	0	0	0	0	$\boxed{0}$	−	$\boxed{0}$	−	0	−	−	0	0
$c^{(2)}_{l^2 e^2 D^2}$	0	0	0	$\boxed{0}$	−	$\boxed{0}$	−	$\boxed{0}$	−	−	−	−	×	×

Full electroweak SMEFT (with no flavour)

	$c^{(1)}_{\phi^4 D^4}$	$c^{(2)}_{\phi^4 D^4}$	$c^{(3)}_{\phi^4 D^4}$	$\tilde{c}^{(1)}_{e^2\phi^2 D^3}$	$\tilde{c}^{(2)}_{e^2\phi^2 D^3}$	$\tilde{c}^{(1)}_{l^2\phi^2 D^3}$	$\tilde{c}^{(2)}_{l^2\phi^2 D^3}$	$\tilde{c}^{(3)}_{l^2\phi^2 D^3}$	$\tilde{c}^{(4)}_{l^2\phi^2 D^3}$	$c_{e^4 D^2}$	$c^{(1)}_{l^4 D^2}$	$c^{(2)}_{l^4 D^2}$	$c^{(1)}_{l^2 e^2 D^2}$	$c^{(2)}_{l^2 e^2 D^2}$
$c^{(1)}_{B^2\phi^2 D^2}$	$\frac{g^2}{3}$	$\frac{g^2}{2}$	$\frac{g^2}{6}$	$\boxed{0}$	−	$\boxed{0}$	−	$\boxed{0}$	−	0	0	0	0	0
$c^{(1)}_{W^2\phi^2 D^2}$	+	+	+	0	0	$\boxed{0}$	−	$\boxed{0}$	−	0	0	0	0	0
$\tilde{c}^{(2)}_{e^2\phi^2 D^3}$	+	+	+	×	×	$\boxed{0}$	−	$\boxed{0}$	−	−	0	0	$\boxed{0}$	−
$\tilde{c}^{(2)}_{l^2\phi^2 D^3}$	+	+	+	$\boxed{0}$	−	×	×	×	×	0	−	−	$\boxed{0}$	−
$\tilde{c}^{(4)}_{l^2\phi^2 D^3}$	+	+	+	$\boxed{0}$	−	×	×	×	×	0	−	−	$\boxed{0}$	−
$c_{e^2 B^2 D}$	0	0	0	$\boxed{0}$	−	0	0	0	0	−	0	0	$\boxed{0}$	−
$c_{l^2 B^2 D}$	0	0	0	0	0	$\boxed{0}$	−	$\boxed{0}$	−	0	−	−	$\boxed{0}$	−
$c_{e^2 W^2 D}$	0	0	0	$\boxed{0}$	−	0	0	0	0	0	0	0	$\boxed{0}$	−
$c^{(1)}_{l^2 W^2 D}$	0	0	0	0	0	$\boxed{0}$	−	$\boxed{0}$	−	0	−	−	0	0
$c^{(2)}_{l^2 e^2 D^2}$	0	0	0	$\boxed{0}$	−	$\boxed{0}$	−	$\boxed{0}$	−	−	−	−	×	×

Full electroweak SMEFT (with no flavour)

	$c^{(1)}_{\phi^4D^4}$	$c^{(2)}_{\phi^4D^4}$	$c^{(3)}_{\phi^4D^4}$	$\tilde{c}^{(1)}_{e^2\phi^2D^3}$	$\tilde{c}^{(2)}_{e^2\phi^2D^3}$	$\tilde{c}^{(1)}_{l^2\phi^2D^3}$	$\tilde{c}^{(2)}_{l^2\phi^2D^3}$	$\tilde{c}^{(3)}_{l^2\phi^2D^3}$	$\tilde{c}^{(4)}_{l^2\phi^2D^3}$	$c_{e^4D^2}$	$c^{(1)}_{l^4D^2}$	$c^{(2)}_{l^4D^2}$	$c^{(1)}_{l^2e^2D^2}$	$c^{(2)}_{l^2e^2D^2}$
$c^{(1)}_{B^2\phi^2D^2}$	$\frac{g^2}{3}$	$\frac{g^2}{2}$	$\frac{g^2}{6}$	$\boxed{0}$	−	$\boxed{0}$	−	$\boxed{0}$	−	0	0	0	0	0
$c^{(1)}_{W^2\phi^2D^2}$	+	+	+	0	0	$\boxed{0}$	−	$\boxed{0}$	−	0	0	0	0	0
$\tilde{c}^{(2)}_{e^2\phi^2D^3}$	+	+	+	×	×	$\boxed{0}$	$-\frac{4\|Y\|^2}{3}$	$\boxed{0}$	−	−	0	0	$\boxed{0}$	−
$\tilde{c}^{(2)}_{l^2\phi^2D^3}$	+	+	+	$\boxed{0}$	−	×	×	×	×	0	−	−	$\boxed{0}$	−
$\tilde{c}^{(4)}_{l^2\phi^2D^3}$	+	+	+	$\boxed{0}$	−	×	×	×	×	0	−	−	$\boxed{0}$	−
$c_{e^2B^2D}$	0	0	0	$\boxed{0}$	−	0	0	0	0	−	0	0	$\boxed{0}$	−
$c_{l^2B^2D}$	0	0	0	0	0	$\boxed{0}$	−	$\boxed{0}$	−	0	−	−	$\boxed{0}$	−
$c_{e^2W^2D}$	0	0	0	$\boxed{0}$	−	0	0	0	0	0	0	0	$\boxed{0}$	−
$c^{(1)}_{l^2W^2D}$	0	0	0	0	0	$\boxed{0}$	−	$\boxed{0}$	−	0	−	−	0	0
$c^{(2)}_{l^2e^2D^2}$	0	0	0	$\boxed{0}$	−	$\boxed{0}$	−	$\boxed{0}$	−	−	−	−	×	×

Full electroweak SMEFT (with no flavour)

	$c^{(1)}_{\phi^4 D^4}$	$c^{(2)}_{\phi^4 D^4}$	$c^{(3)}_{\phi^4 D^4}$	$\tilde{c}^{(1)}_{e^2\phi^2 D^3}$	$\tilde{c}^{(2)}_{e^2\phi^2 D^3}$	$\tilde{c}^{(1)}_{l^2\phi^2 D^3}$	$\tilde{c}^{(2)}_{l^2\phi^2 D^3}$	$\tilde{c}^{(3)}_{l^2\phi^2 D^3}$	$\tilde{c}^{(4)}_{l^2\phi^2 D^3}$	$c_{e^4 D^2}$	$c^{(1)}_{l^4 D^2}$	$c^{(2)}_{l^4 D^2}$	$c^{(1)}_{l^2 e^2 D^2}$	$c^{(2)}_{l^2 e^2 D^2}$
$c^{(1)}_{B^2\phi^2 D^2}$	$\frac{g^2}{3}$	$\frac{g^2}{2}$	$\frac{g^2}{6}$	$\boxed{0}$	$-$	$\boxed{0}$	$-$	$\boxed{0}$	$-$	0	0	0	0	0
$c^{(1)}_{W^2\phi^2 D^2}$	+	+	+	0	0	$\boxed{0}$	$-$	$\boxed{0}$	$-$	0	0	0	0	0
$\tilde{c}^{(2)}_{e^2\phi^2 D^3}$	+	+	+	$g^2 - \lvert Y\rvert^2$	×	$\boxed{0}$	$-\frac{4\lvert Y\rvert^2}{3}$	$\boxed{0}$	$-$	$-$	0	0	$\boxed{0}$	$-$
$\tilde{c}^{(2)}_{l^2\phi^2 D^3}$	+	+	+	$\boxed{0}$	$-$	×	×	×	×	0	$-$	$-$	$\boxed{0}$	$-$
$\tilde{c}^{(4)}_{l^2\phi^2 D^3}$	+	+	+	$\boxed{0}$	$-$	×	×	×	×	0	$-$	$-$	$\boxed{0}$	$-$
$c_{e^2 B^2 D}$	0	0	0	$\boxed{0}$	$-$	0	0	0	0	$-$	0	0	$\boxed{0}$	$-$
$c_{l^2 B^2 D}$	0	0	0	0	0	$\boxed{0}$	$-$	$\boxed{0}$	$-$	0	$-$	$-$	$\boxed{0}$	$-$
$c_{e^2 W^2 D}$	0	0	0	$\boxed{0}$	$-$	0	0	0	0	0	0	0	$\boxed{0}$	$-$
$c^{(1)}_{l^2 W^2 D}$	0	0	0	0	0	$\boxed{0}$	$-$	$\boxed{0}$	$-$	0	$-$	$-$	0	0
$c^{(2)}_{l^2 e^2 D^2}$	0	0	0	$\boxed{0}$	$-$	$\boxed{0}$	$-$	$\boxed{0}$	$-$	$-$	$-$	$-$	×	×

Can't we just compute all anomalous dimensions in some automated way?

Tools like matchmakereft or matchete not yet fully automatic

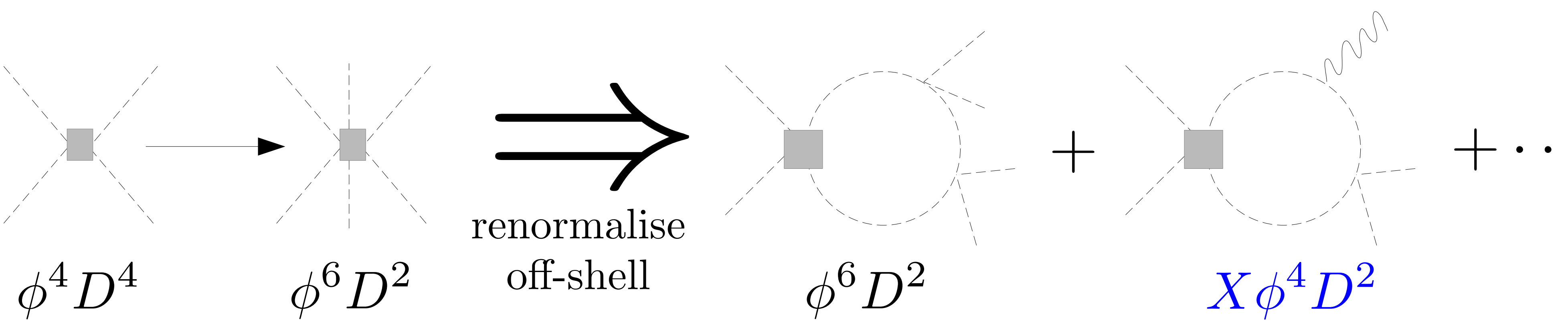
[Carmona et al ' 21; Fuentes-Martin et al '22]

EFT in UV

FeynRules
QGRAF
FORM

EFT in IR

Main obstacles: Green's and physical bases [**MC**, Diaz-Carmona, Guedes '21; Ren, Yu '22; Fonseca]; field redefinitions [**MC**, Santiago]

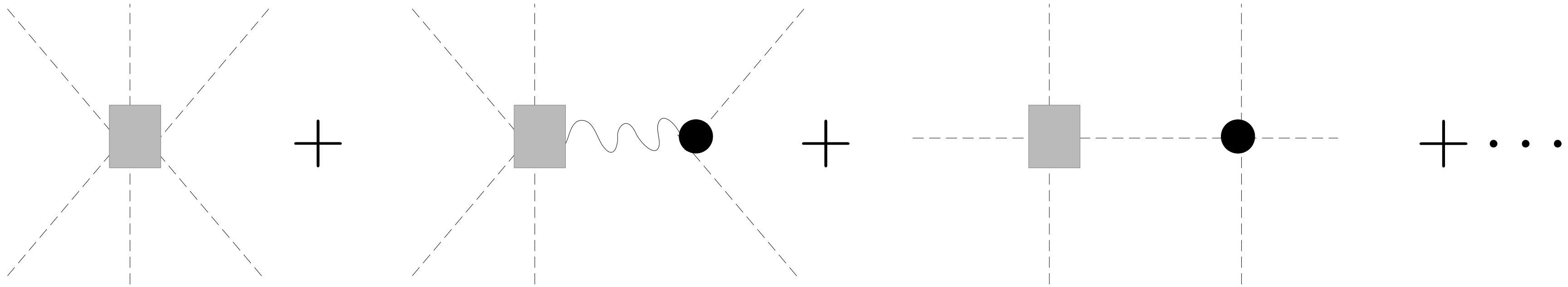


$$L_{\text{div}}^{(\text{local})} \sim \frac{1}{\epsilon} P(p_i \cdot p_j, p_i \cdot \epsilon_j, \cdots)$$

Require Lagrangian with redundant operators to provide same S-matrix as that without them

Too many constraints on-shell. Solution: go numerics

Compute the amplitudes in different Montecarlo physical phase-space points. Problem reduced to linear algebra



Application to the purely Higgs sector [to appear in SMEFT-Tools 2022 proceedings]:

$$c_{\phi\Box} \to c_{\phi\Box} + \frac{1}{2} r'_{\phi D} \,, \tag{22}$$

$$c_{\phi^6} \to c_{\phi^6} + 2\lambda r'_{\phi D} \,, \tag{23}$$

$$c^{(1)}_{\phi^6 D^2} \to c^{(1)}_{\phi^6 D^2} + 2\lambda\left(2 r^{(12)}_{\phi^4 D^4} - 2 r^{(4)}_{\phi^4 D^4} - r^{(6)}_{\phi^4 D^4}\right) - 4 c_{\phi\Box} r'_{\phi D} - \frac{1}{2} c_{\phi D} r'_{\phi D} - \frac{7}{4} r'^2_{\phi D} + r''^2_{\phi D} \,, \tag{24}$$

$$c^{(2)}_{\phi^6} \to c^{(2)}_{\phi^6} + 2\lambda\left(r^{(12)}_{\phi^4 D^4} - r^{(6)}_{\phi^4 D^4}\right) - c_{\phi D} r'_{\phi D} \,. \tag{25}$$

Outlook

Renormalising the SMEFT to dimension 8 is a heavy task, but which can be automatised.

Positivity bounds on dimension-8 interactions (which are important/interesting by themselves) restrict different aspects of (certain) anomalous dimensions (zeros, signs, inequalities).

Further applications include full SMEFT [MC, Li 'ongoing work], LEFT and other EFTs.

Phenomenological relevance of dimension-8 quantum corrections still to be fully understood.

Thank you!