Constraints on anomalous dimensions from the positivity of the S-matrix

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(University of Granada)

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

HEFT 2023, Manchester; June 19, 2023

Partial results on SMEFT RGEs to dimension eight:

See Supratim's talk

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	$X_L^3H^2$, $X_L^2\psi^2H$, $X_L\psi^4$	$X_L^2H^4$, $X_L\psi^2H^3$, ψ^4H^2	ψ^2H^5	H^8
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				$X_R^2H^2D^2$, $X_R^2\psi\bar{\psi}D$, $X_R\bar{\psi}^2HD^2$, $\bar{\psi}^4D^2$	$X_R^3H^2$, $X_R^2\bar{\psi}^2H$, $X_R\bar{\psi}^4$
0					X_R^4

Murphy ‘20;
based on Craig et al ‘20

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8	X_L^4	$X_L^3H^2$, $X_L^2\psi^2H$, $X_L\psi^4$	$X_L^2H^4$, $X_L\psi^2H^3$, ψ^4H^2	ψ^2H^5	H^8
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				$X_R^2H^2D^2$, $X_R^2\psi\bar{\psi}D$, $X_R\bar{\psi}^2HD^2$, $\bar{\psi}^4D^2$	$X_R^3H^2$, $X_R^2\bar{\psi}^2H$, $X_R\bar{\psi}^4$
0					X_R^4

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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

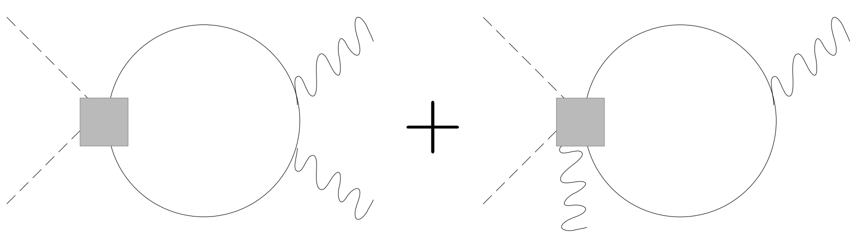
It is obvious that there are zeros in mixing of specific operators of different classes

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

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

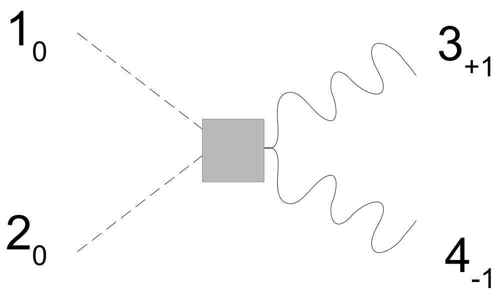
$$\mathcal{O}^{(1)}_{B^2\phi^2D^2} = (D^\mu\phi^\dagger D^\nu\phi)B_{\mu\rho}B^\rho_\nu$$

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

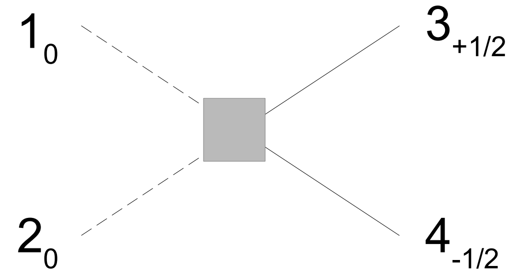


$+\cdots$

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

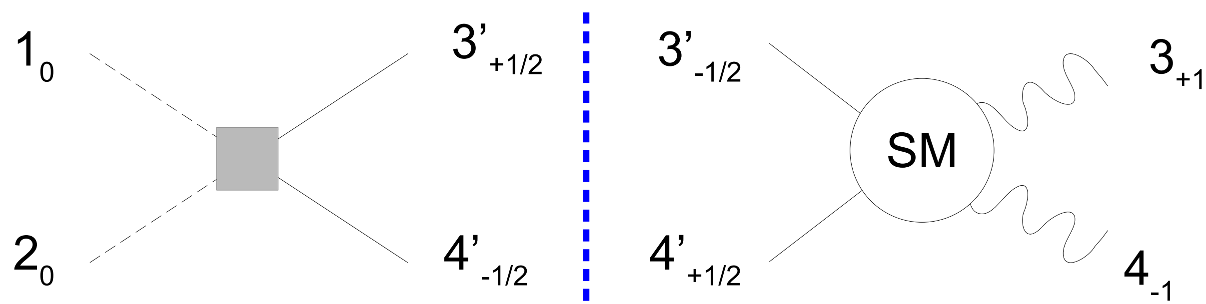


$$= \langle 41\rangle^2[31]^2$$



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

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

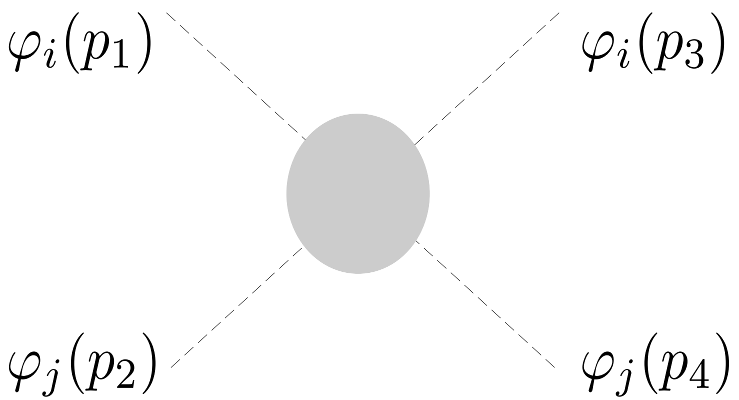


$$= \int d\text{LIPS}\langle 4'3'\rangle\langle 4'1\rangle[4'3'][3'1]\frac{\langle 3'4\rangle^2}{\langle 3'3\rangle\langle 34'\rangle}$$

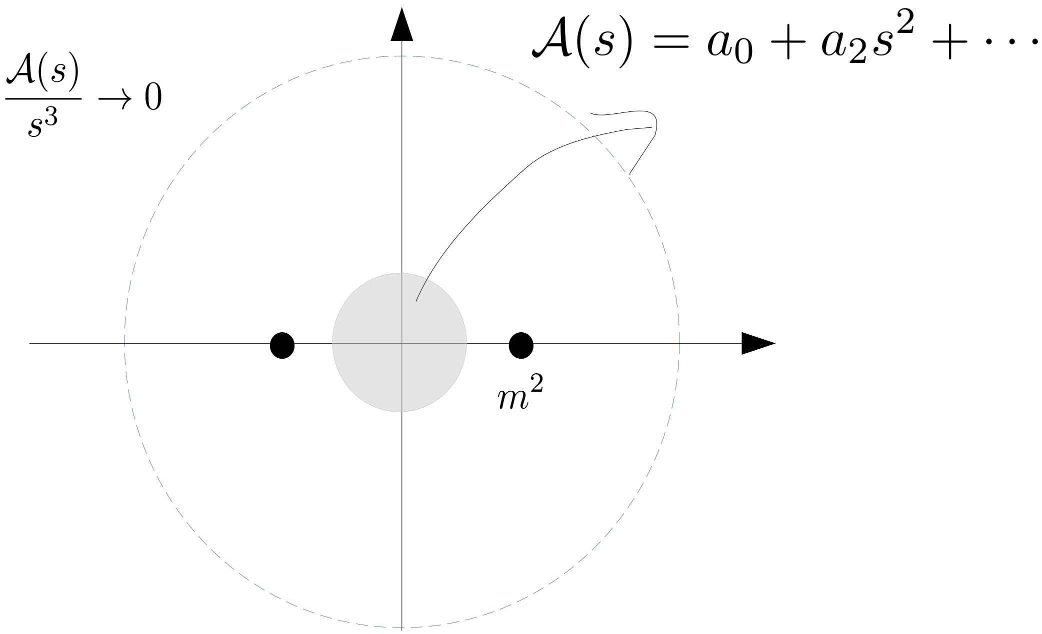
$$= \int_0^{2\pi} d\phi \int_0^{\pi/2} d\theta s_\theta c_\theta \left[\#_1 e^{i\phi} + \#_2 e^{2i\phi} + \cdots\right]$$

0

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

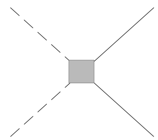


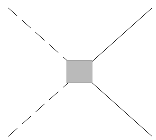
$\mathcal{A}(s) \equiv \mathcal{A}(s, t=0)$

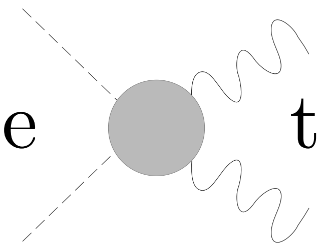


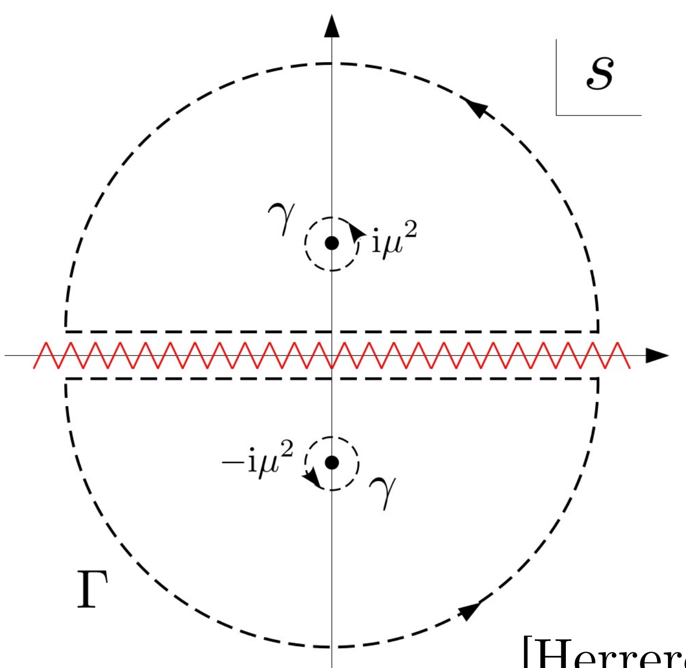
$$0 = \sum \mathrm{res} \frac{\mathcal{A}(s)}{s^3} = a_2 - \frac{1}{\pi} \int s \frac{\sigma(s)}{(m^2)^3} \Rightarrow a_2 > 0$$

See Marc's talk

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.

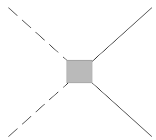
1. For any $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ (and lower-dimensional  ones) at tree level.

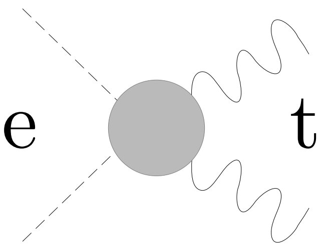
2. Within any such UV, compute  to order $\mathrm{O}(g^2)$

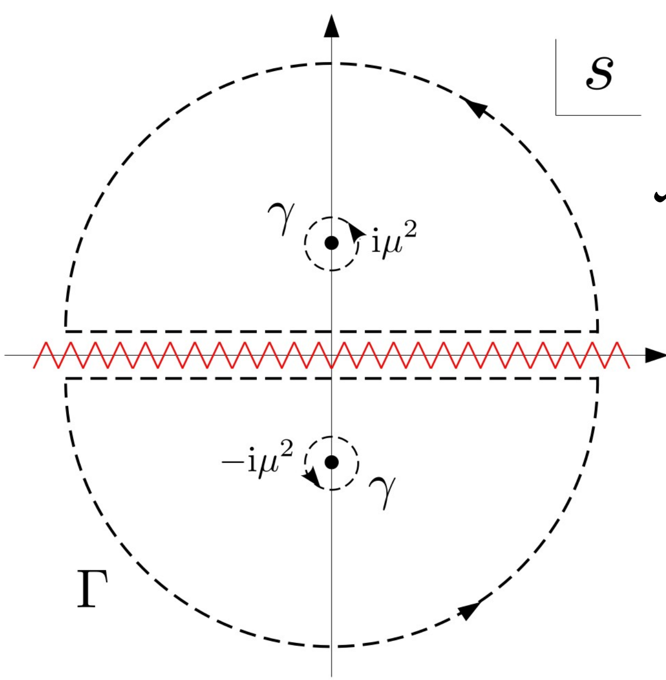


$$\Sigma(\mu) \equiv \frac{1}{2\pi \mathrm{i}} \int_\gamma \frac{\mathcal{A}(s) s^3}{(s^2 + \mu^4)^3} \geq 0$$

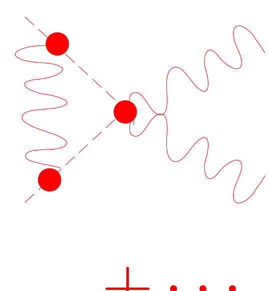
[Herrero-Valea et al ‘20]

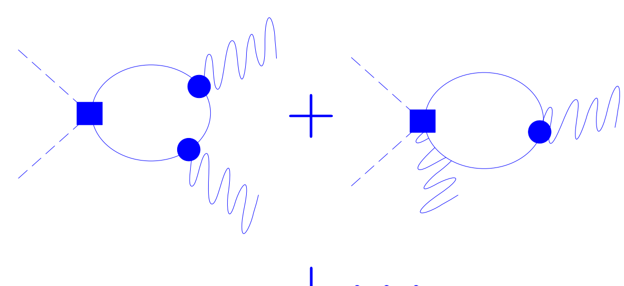
1. For any $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ (and lower-dimensional  ones) at tree level.

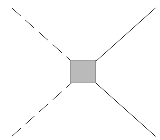
2. Within any such UV, compute  to order $O(g^2)$

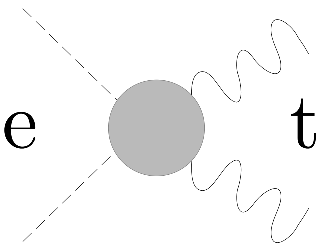


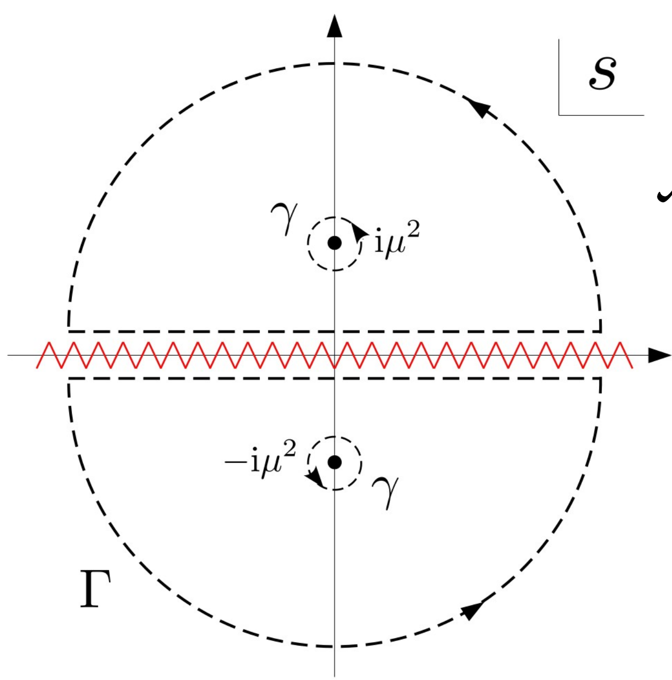
$$\mathcal{A}(s) \sim -(\beta_4 + \beta_8 s^2 + \beta_{12} s^4 + \cdots) \log \frac{s}{\Lambda^2}$$





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 $O(g^2)$



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

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

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

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 $c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$

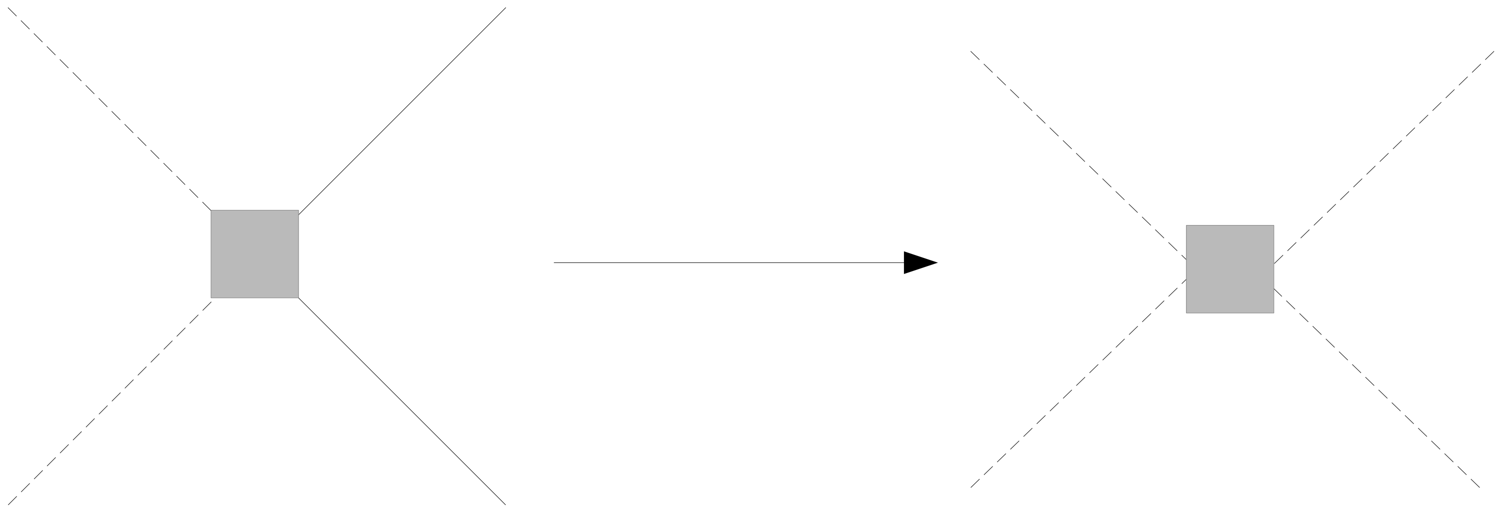
3. The beta function is linear in the Wilson coefficients:

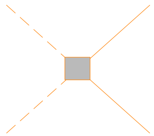
$$\beta_8 = \alpha(c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3}) \,, \quad \alpha \geq 0$$

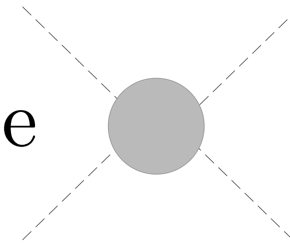
Therefore,

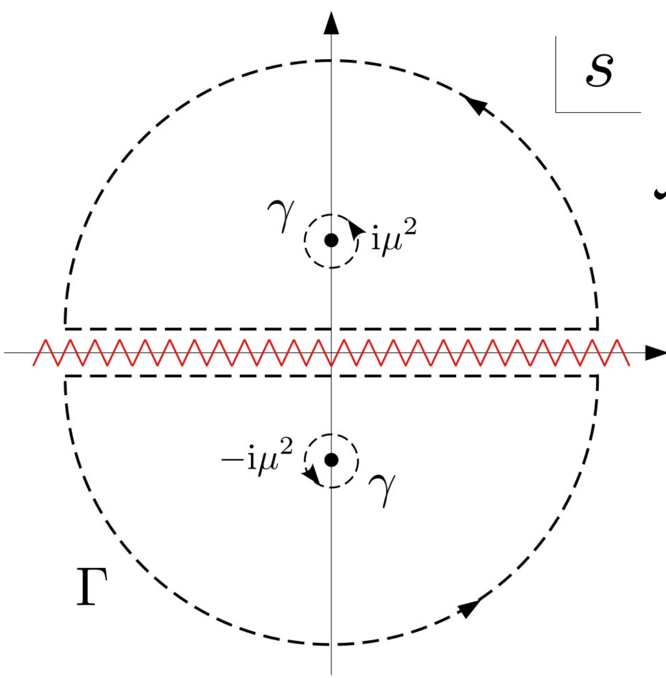
$$\underbrace{\mathcal{O}^{(1)}_{e^2\phi^2 D^3} - \mathcal{O}^{(2)}_{e^2\phi^2 D^3}}_{\widetilde{\mathcal{O}}^{(1)}_{e^2\phi^2 D^3}} \not\longrightarrow \mathcal{O}^{(1)}_{B^2\phi^2 D^2}$$

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

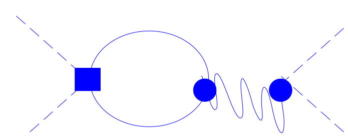


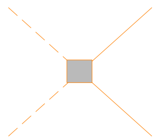
1. For any $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ (and lower-dimensional  ones) at tree level.

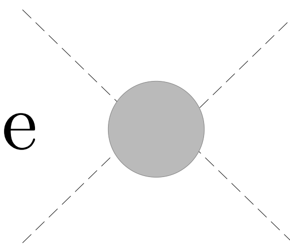
2. Within any such UV, compute  to order $O(g^2)$

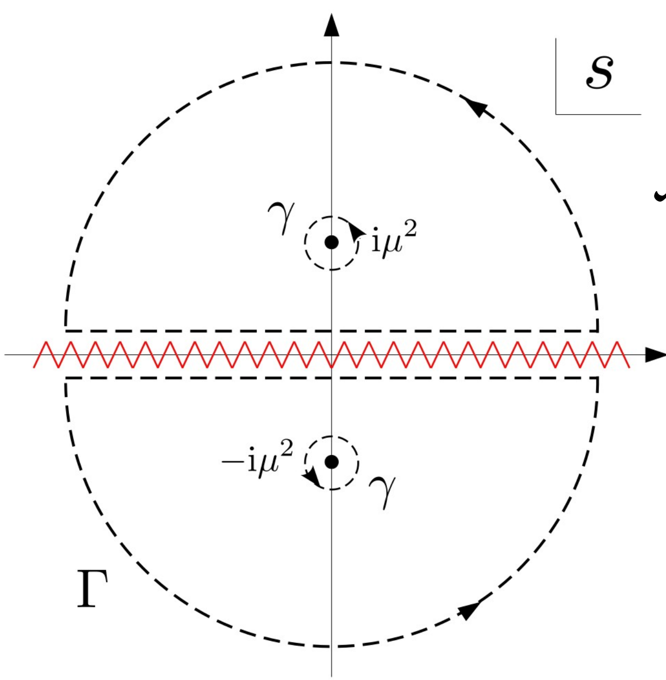


$$\mathcal{A}(s) \sim -(\beta_4 + \beta_8 s^2 + \beta_{12} s^4 + \cdots) \log \frac{s}{\Lambda^2}$$

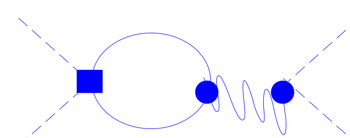
$\cdots$  $+ \cdots$

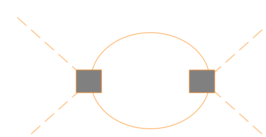
1. For any $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ compatible with the positivity bounds ($c^{(1)}_{e^2\phi^2 D^3} + c^{(2)}_{e^2\phi^2 D^3} \leq 0$) , there exists UV such that only $(c^{(1)}_{e^2\phi^2 D^3}, c^{(2)}_{e^2\phi^2 D^3})$ (and lower-dimensional  ones) at tree level.

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

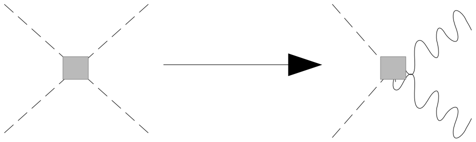


$$\mathcal{A}(s) \sim -(\beta_4 + \beta_8 s^2 + \beta_{12} s^4 + \cdots)\log\frac{s}{\Lambda^2}$$

...  $+ \cdots$

$+$ 

Other aspects of anomalous dimensions: signs and inequalities

Let us consider the mixing 

Positivity bounds:

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

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

From where we obtain:

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

Other aspects of anomalous dimensions: signs and inequalities

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

1. The anomalous dimensions are positive

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

2. They fulfill

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

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)

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

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

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]

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

See Alvaro’s talk

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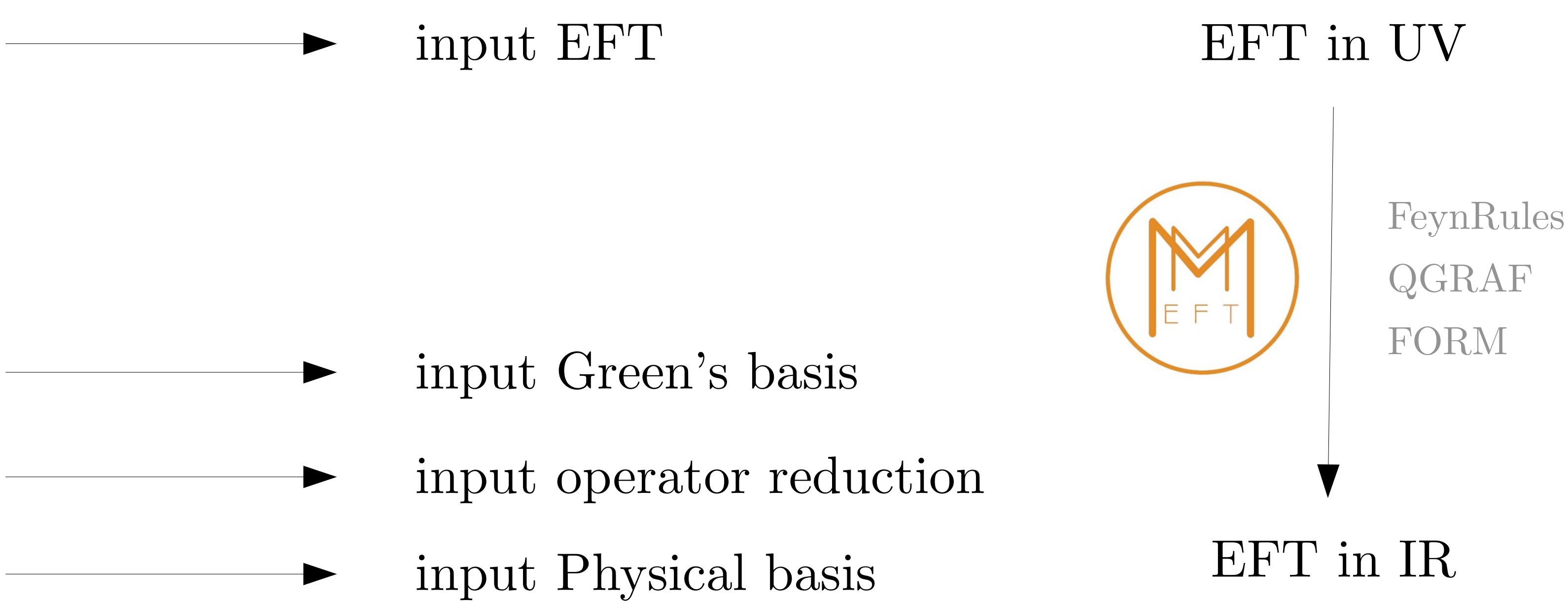

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→ input EFT

EFT in UV

FeynRules
QGRAF
FORM

→ input Green's basis

→ input operator reduction

→ input Physical basis

EFT in IR

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input EFT

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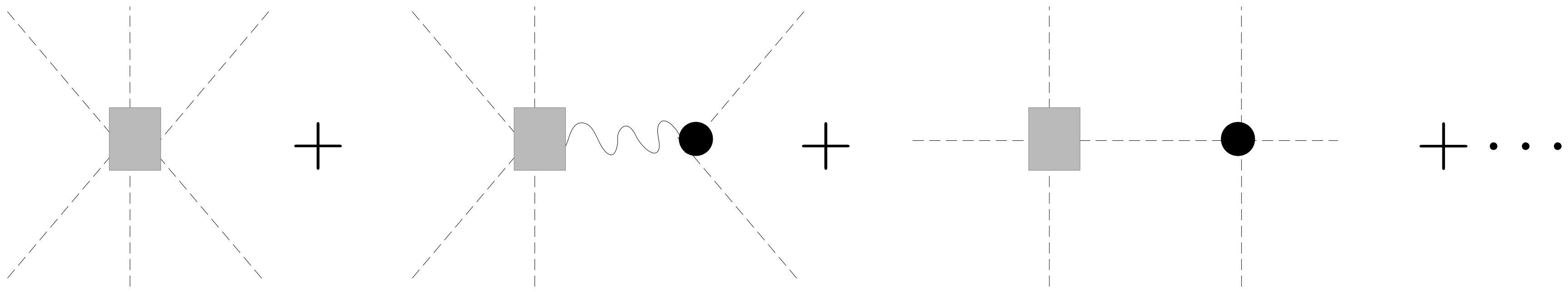
EFT in IR

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]:

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

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

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

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

Outlook

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.

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

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Thank you!