One-Loop UV/IR SMEFT dictionary

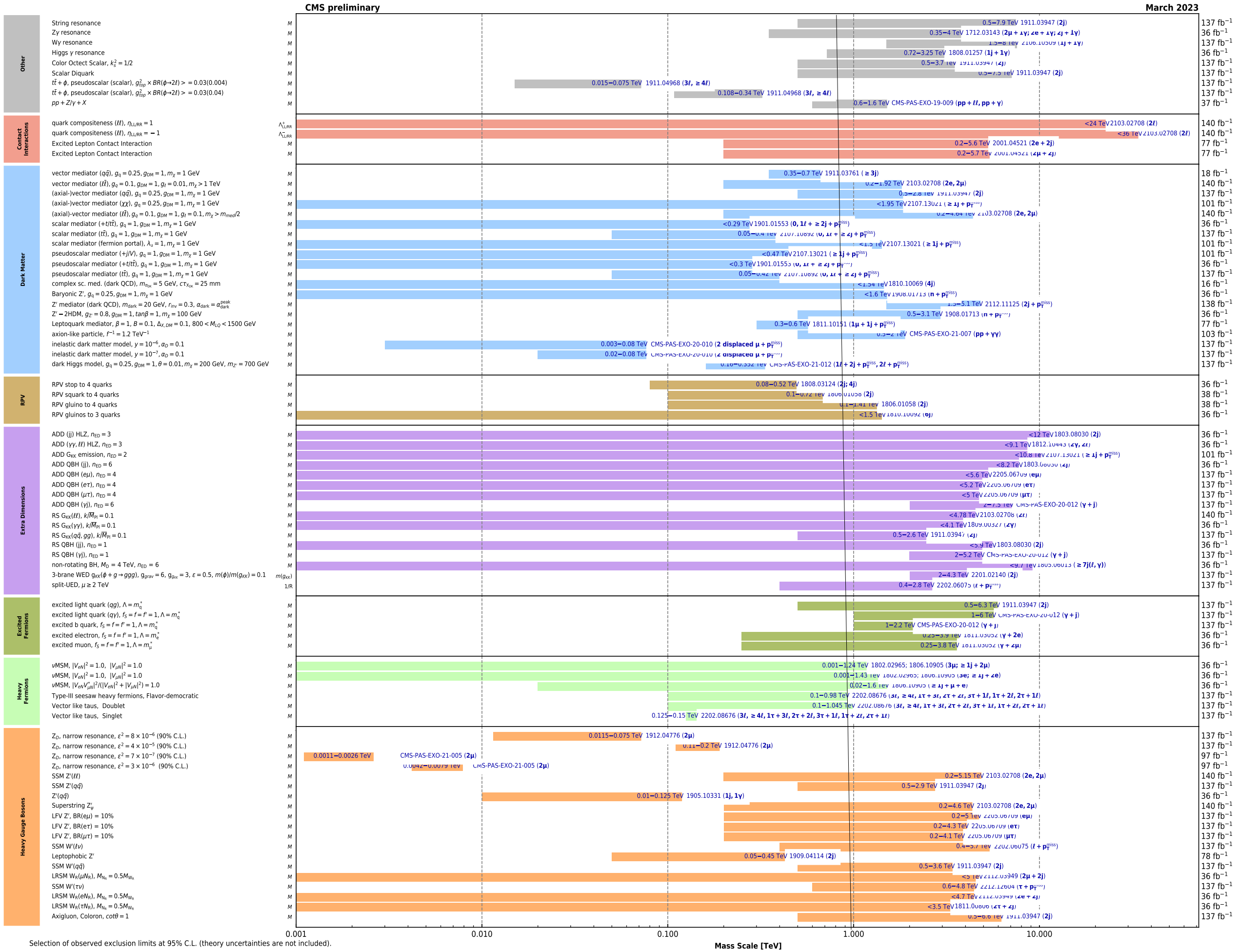
Based on 2303.16965

G. Guedes, J. Santiago, P. Olgoso

guilherme.guedes@desy.de

TeV

Overview of CMS EXO results



The SMEFT

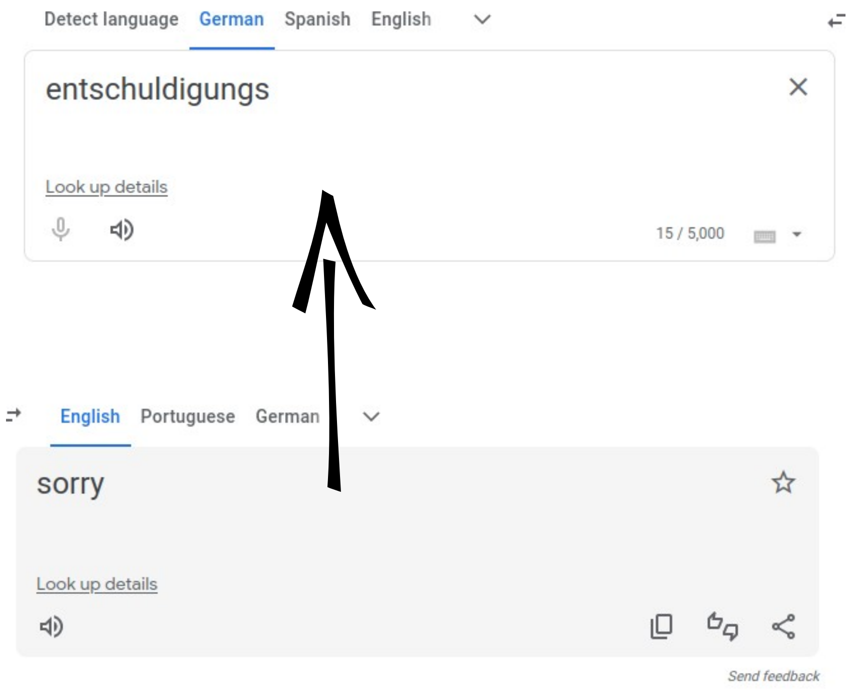
Expansion into higher dimensional operators:

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \frac{\mathcal{L}_6}{\Lambda^2} + \mathcal{O}(1/\Lambda^4)$$

$$\mathcal{L}_d = c_i \mathcal{O}_i$$
$$[\mathcal{O}_i] = d$$

- **Bottom-up approach**: write low-energy observables in terms of effective coefficients, no mention of the UV details.
- **Top-down approach**: calculate value of wilson coefficients for particular UV scenarios.

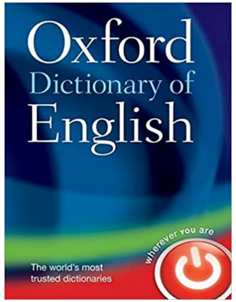
Bottom-up approach: UV/IR dictionaries



Bottom-up approach: UV/IR dictionaries

$$\mathcal{L}_{UV}$$

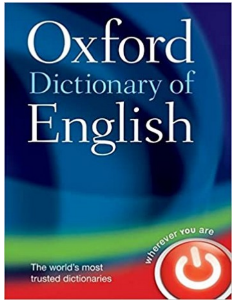
$$\Big\uparrow$$



$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \frac{\mathcal{L}_6}{\Lambda^2}$$

Bottom-up approach: UV/IR dictionaries

$$\mathcal{L}_{UV}$$



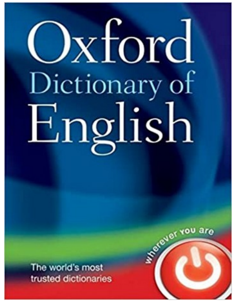
$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \frac{\mathcal{L}_6}{\Lambda^2}$$

- What is the data telling us?
- UV/IR dictionaries tell us ***all*** SM extensions which can contribute to a particular experimental observable (at an order in the EFT expansion)

Top-down approach: UV/IR dictionaries

$$\mathcal{L}_{UV}$$

$$\Big\downarrow$$

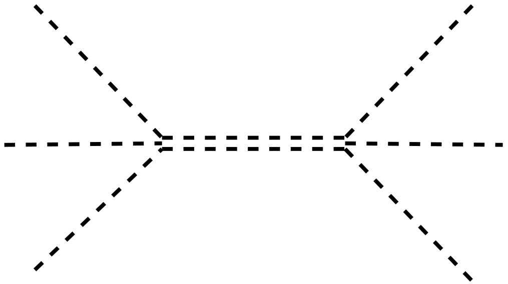


$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \frac{\mathcal{L}_6}{\Lambda^2}$$

- What are the low-energy consequences of a particular UV scenario?
- UV/IR dictionaries allows to map all these contributions finding correlations among WCs.
  - Done at a specific perturbative order through matching.

Dictionary at tree-level

- Tree-level dictionary to the SMEFT @ dim-6 already exists, with ***all*** possible extensions which can generate WCs and their explicity contribution.



$\mathcal{S}$	$\mathcal{S}_1$	$\mathcal{S}_2$	φ	Ξ	Ξ_1	Θ_1	Θ_3
$(1,1)_0$	$(1,1)_1$	$(1,1)_2$	$(1,2)_{\frac{1}{2}}$	$(1,3)_0$	$(1,3)_1$	$(1,4)_{\frac{1}{2}}$	$(1,4)_{\frac{3}{2}}$
ω_1	ω_2	ω_4	Π_1	Π_7	ζ		
$(3,1)_{-\frac{1}{3}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{-\frac{4}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{\frac{7}{6}}$	$(3,3)_{-\frac{1}{3}}$		
Ω_1	Ω_2	Ω_4	Υ	Φ			
$(6,1)_{\frac{1}{3}}$	$(6,1)_{-\frac{2}{3}}$	$(6,1)_{\frac{4}{3}}$	$(6,3)_{\frac{1}{3}}$	$(8,2)_{\frac{1}{2}}$			

N	E	Δ_1	Δ_3	Σ	Σ_1	
$(1,1)_0$	$(1,1)_{-1}$	$(1,2)_{-\frac{1}{2}}$	$(1,2)_{-\frac{3}{2}}$	$(1,3)_0$	$(1,3)_{-1}$	
U	D	Q_1	Q_5	Q_7	T_1	T_2
$(3,1)_{\frac{2}{3}}$	$(3,1)_{-\frac{1}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,2)_{\frac{7}{6}}$	$(3,3)_{-\frac{1}{3}}$	$(3,3)_{\frac{2}{3}}$

$\mathcal{B}$	$\mathcal{B}_1$	$\mathcal{W}$	$\mathcal{W}_1$	$\mathcal{G}$	$\mathcal{G}_1$	$\mathcal{H}$	$\mathcal{L}_1$
$(1,1)_0$	$(1,1)_1$	$(1,3)_0$	$(1,3)_1$	$(8,1)_0$	$(8,1)_1$	$(8,3)_0$	$(1,2)_{\frac{1}{2}}$
$\mathcal{L}_3$	$\mathcal{U}_2$	$\mathcal{U}_5$	$\mathcal{Q}_1$	$\mathcal{Q}_5$	$\mathcal{X}$	$\mathcal{Y}_1$	$\mathcal{Y}_5$
$(1,2)_{-\frac{3}{2}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,3)_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

De Blas, Criado, Perez-Victoria, Santiago, 1711.10391

Dictionary at tree-level

- Tree-level dictionary to the SMEFT @ dim-6 already exists, with ***all*** possible extensions which can generate WCs and their explicity contribution.
- Some operators can be generated at one-loop
  - Considering weakly coupled renormalizable UV

Craig, Jiang, Li, Sutherland 2001.00017

$\mathcal{S}$	$\mathcal{S}_1$	$\mathcal{S}_2$	φ	Ξ	Ξ_1	Θ_1	Θ_3
$(1,1)_0$	$(1,1)_1$	$(1,1)_2$	$(1,2)_{\frac{1}{2}}$	$(1,3)_0$	$(1,3)_1$	$(1,4)_{\frac{1}{2}}$	$(1,4)_{\frac{3}{2}}$
ω_1	ω_2	ω_4	Π_1	Π_7	ζ		
$(3,1)_{-\frac{1}{3}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{-\frac{4}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{\frac{7}{6}}$	$(3,3)_{-\frac{1}{3}}$		
Ω_1	Ω_2	Ω_4	Υ	Φ			
$(6,1)_{\frac{1}{3}}$	$(6,1)_{-\frac{2}{3}}$	$(6,1)_{\frac{4}{3}}$	$(6,3)_{\frac{1}{3}}$	$(8,2)_{\frac{1}{2}}$			

N	E	Δ_1	Δ_3	Σ	Σ_1	
$(1,1)_0$	$(1,1)_{-1}$	$(1,2)_{-\frac{1}{2}}$	$(1,2)_{-\frac{3}{2}}$	$(1,3)_0$	$(1,3)_{-1}$	
U	D	Q_1	Q_5	Q_7	T_1	T_2
$(3,1)_{\frac{2}{3}}$	$(3,1)_{-\frac{1}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,2)_{\frac{7}{6}}$	$(3,3)_{-\frac{1}{3}}$	$(3,3)_{\frac{2}{3}}$

$\mathcal{B}$	$\mathcal{B}_1$	$\mathcal{W}$	$\mathcal{W}_1$	$\mathcal{G}$	$\mathcal{G}_1$	$\mathcal{H}$	$\mathcal{L}_1$
$(1,1)_0$	$(1,1)_1$	$(1,3)_0$	$(1,3)_1$	$(8,1)_0$	$(8,1)_1$	$(8,3)_0$	$(1,2)_{\frac{1}{2}}$
$\mathcal{L}_3$	$\mathcal{U}_2$	$\mathcal{U}_5$	$\mathcal{Q}_1$	$\mathcal{Q}_5$	$\mathcal{X}$	$\mathcal{Y}_1$	$\mathcal{Y}_5$
$(1,2)_{-\frac{3}{2}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{\frac{5}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{-\frac{5}{6}}$	$(3,3)_{\frac{2}{3}}$	$(\bar{6},2)_{\frac{1}{6}}$	$(\bar{6},2)_{-\frac{5}{6}}$

De Blas, Criado, Perez-Victoria, Santiago, 1711.10391

Dictionary at one-loop

- Current experimental precision needs one-loop matching.
- Significant progress in the past few years in the development of automatic tools to perform matching at one-loop.
  - CoDEx/Matchete – Functional. Das Bakshi, Chakrabortty,Kumar Patra, 1808.04403 Fuentes-Martín, König, Pagès, Thomsen, Wilsch, 2212.04510
  - Matchmakereft – Diagrammatic. Carmona, Lazopoulos, Olgoso, Santiago, 2112.10787
- However, creating a dictionary at this order is not immediate – infinite completions.

The dictionary – first iteration

- Consider operators with **leading** contribution at one-loop (weakly coupled renormalizable UV)
- Limit UV theory to heavy scalars and fermions with renormalizable interactions

X^3	X^2H^2	$\psi^2 XH + \text{h.c.}$
$\mathcal{O}_{3G} = f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$\mathcal{O}_{HG} = G^A_{\mu\nu} G^{A\,\mu\nu} H^\dagger H$	$\mathcal{O}_{uG} = (\bar{q} T^A \sigma^{\mu\nu} u) \widetilde{H} G^A_{\mu\nu}$
$\mathcal{O}_{\widetilde{3G}} = f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$\mathcal{O}_{H\widetilde{G}} = \widetilde{G}^A_{\mu\nu} G^{A\,\mu\nu} H^\dagger H$	$\mathcal{O}_{uW} = (\bar{q} \sigma^{\mu\nu} u) \sigma^I \widetilde{H} W^I_{\mu\nu}$
$\mathcal{O}_{3W} = \epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$\mathcal{O}_{HW} = W^I_{\mu\nu} W^{I\,\mu\nu} H^\dagger H$	$\mathcal{O}_{uB} = (\bar{q} \sigma^{\mu\nu} u) \widetilde{H} B_{\mu\nu}$
$\mathcal{O}_{\widetilde{3W}} = \epsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$\mathcal{O}_{H\widetilde{W}} = \widetilde{W}^I_{\mu\nu} W^{I\,\mu\nu} H^\dagger H$	$\mathcal{O}_{dG} = (\bar{q} T^A \sigma^{\mu\nu} d) H G^A_{\mu\nu}$
	$\mathcal{O}_{HB} = B_{\mu\nu} B^{\mu\nu} H^\dagger H$	$\mathcal{O}_{dW} = (\bar{q} \sigma^{\mu\nu} d) \sigma^I H W^I_{\mu\nu}$
	$\mathcal{O}_{H\widetilde{B}} = \widetilde{B}_{\mu\nu} B^{\mu\nu} H^\dagger H$	$\mathcal{O}_{dB} = (\bar{q} \sigma^{\mu\nu} d) H B_{\mu\nu}$
	$\mathcal{O}_{HWB} = W^I_{\mu\nu} B^{\mu\nu} H^\dagger \sigma^I H$	$\mathcal{O}_{eW} = (\bar{\ell} \sigma^{\mu\nu} e) \sigma^I H W^I_{\mu\nu}$
	$\mathcal{O}_{H\widetilde{W}B} = \widetilde{W}^I_{\mu\nu} B^{\mu\nu} H^\dagger \sigma^I H$	$\mathcal{O}_{eB} = (\bar{\ell} \sigma^{\mu\nu} e) H B_{\mu\nu}$

The dictionary

$$
\begin{aligned}
\mathcal{L}_{\rm UV} =& \delta_{\Psi_a}\bar{\Psi}_a\left[\mathrm{i}\not{D} - M_{\Psi_a}\right]\Psi_a + \delta_{\Phi_a}\left[|D_\mu\Phi_a|^2 - M^2_{\Phi_a}|\Phi_a|^2\right] \\
&+ \sum_{\chi=L,R}\left[Y^\chi_{abc}\overline{\Psi}_a P_\chi \Psi_b \Phi_c + \widetilde{Y}^\chi_{abc}\overline{\Psi}_a P_\chi \Psi_b \Phi^\dagger_c\right. \\
&\qquad\left. + X^\chi_{abc}\overline{\Psi^c}_a P_\chi \Psi_b \Phi_c + \widetilde{X}^\chi_{abc}\overline{\Psi^c}_a P_\chi \Psi_b \Phi^\dagger_c + \text{h.c.}\right] \\
&+ \left[\kappa_{abc}\Phi_a\Phi_b\Phi_c + \kappa'_{abc}\Phi_a\Phi_b\Phi^\dagger_c + \lambda_{abcd}\Phi_a\Phi_b\Phi_c\Phi_d\right. \\
&\quad\left. + \ \lambda'_{abcd}\Phi_a\Phi_b\Phi_c\Phi^\dagger_d + \lambda''_{abcd}\Phi_a\Phi_b\Phi^\dagger_c\Phi^\dagger_d + \text{h.c.}\right],
\end{aligned}
$$

Gauge structure of UV couplings kept arbitrary.
Match using matchmakereft

The dictionary

WCs are therefore given in terms of UV couplings and Clebsch-Gordon tensors.

Example: G.G., Olgoso 2205.04480

$$\alpha_{e\gamma}^{2,2} = \frac{iN_c e}{4} y_M y_F y_b^R \sum_{IJ} T_{I2J} \left[\gamma_\Psi T^{\gamma,\Psi}_{I'I} T'_{2JI'} + \gamma_\Phi T^{\gamma,\Phi}_{JJ'} T'_{2IJ'} \right]$$

The next step is to specify **Quantum numbers of UV scenario** – **GroupMath** computes possible CGs

Fonseca 2011.01764

The dictionary

Dictionary can be used through the Mathematica package:
SOLD (Smeft One-Loop Dictionary)

```
In[1]:= << SOLD`

SMEFT One Loop Dictionary loaded
Version: 1.0.1
Authors: Guilherme Guedes, Pablo Olgoso, José Santiago
Reference: arXiv:2303.16965
Webpage: https://gitlab.com/jsantiago_ugr/sold

XXXXXXXXXXXXXXXXXXXXXXXXXXX GroupMath XXXXXXXXXXXXXXXXXXXXXXXXXXX
Version: 1.1.2 (6/May/2020)
Author: Renato Fonseca
Reference: 2011.01764 [hep-th]
Website: renatofonseca.net/groupmath
Built-in documentation: here
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX-
   XXXX
```

The dictionary

Dictionary can be used in two directions:

Bottom-up: Which UV models generate a specific Wilson Coefficient?

Top-Down: Which Wilson coefficients are generated by a specific UV model?

The dictionary

$$\mathcal{O}_{dG} = (\bar{q}_L \sigma^{\mu\nu} T_A d_R)\,\phi G^A_{\mu\nu}$$

Bottom-up: Which UV models generate a specific Wilson Coefficient? Which restrictions?

```
In[2]:= listofmodels = ListModelsWarsaw[alphaOdG[i, j]];
        MatrixForm[Join[Take[listofmodels[[1]], {1, 3}], {{"....", "....", "...."}}, Take[listofmodels[[1]], {20, 22}],
          {{"....", "....", "...."}}, Take[listofmodels[[1]], {145, 146}], {{"....", "....", "...."}}]]
```

Out[3]//MatrixForm=

Field Content	SU(3) ⊗ SU(2)	U(1)
$\{\phi 1\}$	$\{\phi 1 \to \bar{\mathbf{3}} \otimes \mathbf{1}\}$	$\{Y_{\phi 1} \to \frac{1}{3}\}$
$\{\phi 1\}$	$\{\phi 1 \to \bar{\mathbf{3}} \otimes \mathbf{1}\}$	$\{Y_{\phi 1} \to \frac{4}{3}\}$
....	....	....
$\{\phi 1, \phi 2\}$	$\{\phi 1 \to \mathbf{8} \otimes \mathbf{2},\ \phi 2 \otimes \overline{\phi 2} \supset \mathbf{8} \otimes \mathbf{3}\}$	$\{Y_{\phi 1} \to -\frac{1}{2},\ Y_{\phi 2}\}$
$\{\phi 1, \psi 1\}$	$\{\psi 1 \otimes \overline{\phi 1} \supset \bar{\mathbf{3}} \otimes \mathbf{1}\}$	$\{Y_{\psi 1} \to \frac{1}{3} + Y_{\phi 1}\}$
$\{\phi 1, \psi 1\}$	$\{\psi 1 \otimes \overline{\phi 1} \supset \bar{\mathbf{3}} \otimes \mathbf{2}\}$	$\{Y_{\psi 1} \to -\frac{1}{6} + Y_{\phi 1}\}$
....	....	....
$\{\phi 1, \psi 1, \psi 2\}$	$\{\psi 1 \otimes \overline{\phi 1} \supset \bar{\mathbf{3}} \otimes \mathbf{2},\ \psi 1 \otimes \psi 2 \supset \mathbf{1} \otimes \mathbf{2},\ \psi 2 \otimes \phi 1 \supset \mathbf{3} \otimes \mathbf{1}\}$	$\{Y_{\psi 1} \to -\frac{1}{6} + Y_{\phi 1},\ Y_{\psi 2} \to -\frac{1}{3} - Y_{\phi 1}\}$
$\{\phi 1, \psi 1, \psi 2\}$	$\{\psi 1 \otimes \overline{\phi 1} \supset \bar{\mathbf{3}} \otimes \mathbf{2},\ \psi 2 \otimes \overline{\psi 1} \supset \mathbf{1} \otimes \mathbf{2},\ \psi 2 \otimes \overline{\phi 1} \supset \bar{\mathbf{3}} \otimes \mathbf{1}\}$	$\{Y_{\psi 1} \to -\frac{1}{6} + Y_{\phi 1},\ Y_{\psi 2} \to \frac{1}{3} + Y_{\phi 1}\}$
....	....	....

The dictionary

$$\mathcal{O}_{dG} = (\bar{q}_L \sigma^{\mu\nu} T_A d_R)\, \phi G^A_{\mu\nu}$$

Bottom-up: Which UV models generate a specific Wilson Coefficient? Which Quantum Numbers?

```
In[13]:= modelQNs = ListValidQNs[listofmodels[[1, 145]]];
         Print["Model restriction :", listofmodels[[1, 145]], "\nList of Models:\n",
          MatrixForm[Join[Take[modelQNs, {1, 3}], {{"....", "....", "...."}}, Take[modelQNs, {-3, -1}]]]]
```

Model restriction : $\left\{\{\phi 1, \psi 1, \psi 2\}, \{\psi 1 \otimes \overline{\phi 1} \supset \mathbf{3} \otimes \mathbf{2}, \psi 1 \otimes \psi 2 \supset \mathbf{1} \otimes \mathbf{2}, \psi 2 \otimes \phi 1 \supset \mathbf{3} \otimes \mathbf{1}\}, \left\{Y_{\psi 1} \to -\frac{1}{6} + Y_{\phi 1}, Y_{\psi 2} \to -\frac{1}{3} - Y_{\phi 1}\right\}\right\}$

List of Models:

$$\begin{pmatrix}
\phi 1 \to \mathbf{1} \otimes \mathbf{1} \otimes Y_{\phi 1} & \psi 1 \to \overline{\mathbf{3}} \otimes \mathbf{2} \otimes \left(-\frac{1}{6} + Y_{\phi 1}\right) & \psi 2 \to \mathbf{3} \otimes \mathbf{1} \otimes \left(-\frac{1}{3} - Y_{\phi 1}\right) \\
\phi 1 \to \mathbf{1} \otimes \mathbf{2} \otimes Y_{\phi 1} & \psi 1 \to \overline{\mathbf{3}} \otimes \mathbf{1} \otimes \left(-\frac{1}{6} + Y_{\phi 1}\right) & \psi 2 \to \mathbf{3} \otimes \mathbf{2} \otimes \left(-\frac{1}{3} - Y_{\phi 1}\right) \\
\phi 1 \to \mathbf{1} \otimes \mathbf{2} \otimes Y_{\phi 1} & \psi 1 \to \overline{\mathbf{3}} \otimes \mathbf{3} \otimes \left(-\frac{1}{6} + Y_{\phi 1}\right) & \psi 2 \to \mathbf{3} \otimes \mathbf{2} \otimes \left(-\frac{1}{3} - Y_{\phi 1}\right) \\
\cdots\cdot & \cdots\cdot & \cdots\cdot \\
\phi 1 \to \mathbf{15'} \otimes \mathbf{4} \otimes Y_{\phi 1} & \psi 1 \to \mathbf{10} \otimes \mathbf{3} \otimes \left(-\frac{1}{6} + Y_{\phi 1}\right) & \psi 2 \to \overline{\mathbf{10}} \otimes \mathbf{4} \otimes \left(-\frac{1}{3} - Y_{\phi 1}\right) \\
\phi 1 \to \mathbf{15'} \otimes \mathbf{4} \otimes Y_{\phi 1} & \psi 1 \to \mathbf{10} \otimes \mathbf{5} \otimes \left(-\frac{1}{6} + Y_{\phi 1}\right) & \psi 2 \to \overline{\mathbf{10}} \otimes \mathbf{4} \otimes \left(-\frac{1}{3} - Y_{\phi 1}\right) \\
\phi 1 \to \mathbf{15'} \otimes \mathbf{5} \otimes Y_{\phi 1} & \psi 1 \to \mathbf{10} \otimes \mathbf{4} \otimes \left(-\frac{1}{6} + Y_{\phi 1}\right) & \psi 2 \to \overline{\mathbf{10}} \otimes \mathbf{5} \otimes \left(-\frac{1}{3} - Y_{\phi 1}\right)
\end{pmatrix}$$

The dictionary

Top-Down: Which Wilson coefficients are generated by a specific UV model?

```
In[5]:= NiceOutput[
  Limit[
   Match2Warsaw[alphaOdG[i, j], {Sa → {1, 1, Y1}, Fa → {3, 2, (1 / 6) - Y1},
       Fb → {3, 1, -(1 / 3) - Y1}}] /. L1[qLbar, dR, phi][__] → 0 // FullSimplify,
   {MFa → MSa, MFb → MSa}], True]
```

$\{g3 \to g_3,\ MSa \to M_{Sa},\ L1[Fabar, Fb, phi, L] \to \lambda^{[L]}{}_{\overline{Fa},Fb,\phi},\ L1[Fabar, Fb, phi, R] \to \lambda^{[R]}{}_{\overline{Fa},Fb,\phi},$
$L1[qLbar, Fa, Sa][i] \to \lambda_{\overline{qL},Fa,Sa}{}^{[i]},\ L1bar[dRbar, Fb, Sa][j] \to \overline{\lambda}_{\overline{dR},Fb,Sa}{}^{[j]}\}$

Out[5]= $-\dfrac{g_3\left(\lambda^{[L]}{}_{\overline{Fa},Fb,\phi}-3\,\lambda^{[R]}{}_{\overline{Fa},Fb,\phi}\right)\lambda_{\overline{qL},Fa,Sa}{}^{[i]}\,\overline{\lambda}_{\overline{dR},Fb,Sa}{}^{[j]}}{384\,\pi^2 M_{Sa}^2}$

The dictionary – compute all WCs

Automatic creation of **FeynRules** model

Create Lagrangean of UV model

```
In[2]:= CreateLag[{Sa → {{0, 0}, 1, Y1}, Fa → {{0, 1}, 2, -(1/6) + Y1}, Fb → {{1, 0}, 1, -(1/3) - Y1}}]

Out[2]= {Sa² Sabar² λ_{Sa-bar,Sa-bar,Sa,Sa} + Sa DRbar[sp1, ff0, cc0].Fb[sp1, cc1] λ_{dR-bar,Fb,Sa}^[ff0] TC51[cc0, cc1] +
   Sa Sabar Phi[ss2] × Phibar[ss0] λ_{φ-bar,Sa-bar,φ,Sa} TS11[ss0, ss2] +
   CC[Fabar[sp1, ss0, cc0]].left[Fb[sp1, cc1]] × Phi[ss2] λ^[L]_{Fa,Fb,φ} TC31[cc0, cc1] × TS31[ss0, ss2] +
   CC[Fabar[sp1, ss0, cc0]].right[Fb[sp1, cc1]] × Phi[ss2] λ^[R]_{Fa,Fb,φ} TC31[cc0, cc1] × TS31[ss0, ss2] +
   Sabar CC[Fabar[sp1, ss1, cc1]].QL[sp1, ss2, ff0, cc2] λ_{Sa-bar,Fa,qL}^[ff0] TC41[cc1, cc2] × TS41[ss1, ss2],
  {TS11 → {{1, 0}, {0, 1}}, TC31 → {{1, 0, 0}, {0, 1, 0}, {0, 0, 1}}, TS31 → {{0, -1}, {1, 0}},
   TC41 → {{1, 0, 0}, {0, 1, 0}, {0, 0, 1}}, TS41 → {{0, -1}, {1, 0}}, TC51 → {{1, 0, 0}, {0, 1, 0}, {0, 0, 1}}}}
```

Run **Matchmakereft** directly

```
In[9]:= CompleteOneLoopMatching[{Sa->{{0,0},1,Y1},Fa->{{0,1},2,-(1/6)+Y1},
        Fb->{{1,0},1,-(1/3)-Y1}},"model"]
```

Phenomenology

- Next step would be to use **matchmakereft** to compute the matching results and **smelli** to verify the viability of some parameter points

Matchmakereft

Full one loop matching onto the Warsaw basis

&

smelli

Fit to observables

A. Carmona, A. Lazopoulos, P. Olgoso, J. Santiago 2112.10787

J. Aebischer, J. Kumar, P. Stangl, and D. M. Straub 1810.07698

The dictionary – general results

X^3
$\mathcal{O}_{3G} = f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
$\mathcal{O}_{\widetilde{3G}} = f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
$\mathcal{O}_{3W} = \epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
$\mathcal{O}_{\widetilde{3W}} = \epsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$

$$\alpha_{3V} = -\frac{1}{(4\pi)^2} \sum_R \frac{c_R\, g^3}{90 M_R^2} \mu(R), \quad c_R = \begin{cases} 1, & \text{Dirac fermions} \\ \frac{1}{2}, & \text{Majorana fermions} \\ -\frac{1}{2}, & \text{complex scalars} \\ -\frac{1}{4}, & \text{real scalars} \end{cases}$$

$$\mathrm{Tr}(T_R^A T_R^B) = \mu(R)\delta^{AB}$$

Conclusions

- The effective approach allows us to parametrize low-energy observables through WCs with no mention of UV
- UV/IR dictionaries allow us to efficiently connect these WCs (and therefore observables) with **ALL** possible UV origins
- Dictionaries can work as a guiding principle
- Since one-loop effects are relevant, dictionary at this order should be computed: **`SOLD`**

Thanks

guilherme.guedes@desy.de