The SMEFTsim package

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The SMEFTsim package: purpose

have a **UFO & FeynRules tool** with:

1. the complete Warsaw basis for 3 generations, including all complex phases and ~~CP~~ terms
2. automatic implementation of field redefinitions to have canonical kinetic terms
3. automatic implementation of parameters shifts due to the choice of an input parameters set

→ a Lagrangian that can be directly used for phenomenology:

- analytic computations in FeynRules/FeynArts/FormCalc
- montecarlo generation in MadGraph5

Main scope:

estimate **tree-level interference** terms between SM and $d = 6$ corrections

→ accuracy $\sim$ %

More in detail: field redefinitions

Gauge bosons

$$\mathcal{L}_{\rm SMEFT} \supset -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W^I_{\mu\nu}W^{I\mu\nu} - \frac{1}{4}G^a_{\mu\nu}G^{a\mu\nu} + $$
$$+ C_{HB}(H^\dagger H)B_{\mu\nu}B^{\mu\nu} + C_{HW}(H^\dagger H)W^I_{\mu\nu}W^{I\mu\nu} + C_{HWB}(H^\dagger \sigma^I H)W^I_{\mu\nu}B^{\mu\nu}$$
$$+ C_{HG}(H^\dagger H)G^a_{\mu\nu}G^{a\mu\nu}$$

to have **canonically normalized kinetic terms** we need to

1. redefine fields and couplings keeping (gV_μ) unchanged:

$$\mathcal{B}_\mu \to B_\mu(1 + C_{HB}v^2) \qquad g_1 \to g_1(1 - C_{HB}v^2)$$
$$\mathcal{W}^I_\mu \to W^I_\mu(1 + C_{HW}v^2) \qquad g_2 \to g_2(1 - C_{HW}v^2)$$
$$\mathcal{G}^a_\mu \to G^a_\mu(1 + C_{HG}v^2) \qquad g_s \to g_s(1 - C_{HG}v^2)$$

2. correct the rotation to mass eigenstates:

$$\begin{pmatrix}\mathcal{W}^3_\mu \\ \mathcal{B}_\mu\end{pmatrix} = \begin{pmatrix}1 & -v^2 C_{HWB}/2 \\ -v^2 C_{HWB}/2 & 1\end{pmatrix}\begin{pmatrix}\cos\theta & \sin\theta \\ -\sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix}Z_\mu \\ A_\mu\end{pmatrix}$$

(equivalent to a shift of the Weinberg angle)

Alonso,Jenkins,Manohar,Trott 1312.2014

More in detail: field redefinitions

Higgs

$$\mathcal{L}_{\rm SMEFT} \supset \frac{1}{2} D_\mu H^\dagger D^\mu H + C_{H\Box}(H^\dagger H)(H^\dagger \Box H) + C_{HD}(H^\dagger D_\mu H)^*(H^\dagger D^\mu H)$$

to have a canonically normalized kinetic term, in unitary gauge, we need to replace

$$h \to h\left(1 + v^2 C_{H\Box} - \frac{v^2}{4} C_{HD}\right)$$

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These redefinitions are embedded by default in the SMEFTsim models

Alonso,Jenkins,Manohar,Trott 1312.2014

More in detail: parameter shifts from input choice

SM case.

Parameters in the canonically normalized Lagrangian : $\bar{v}, \bar{g}_1, \bar{g}_2, s_{\bar{\theta}}$

The values can be inferred from the measurements e.g. of $\{\alpha_{\rm em}, m_Z, G_f\}$:

$$\alpha_{\rm em} = \frac{\bar{g}_1\bar{g}_2}{\bar{g}_1^2+\bar{g}_2^2} \qquad m_Z = \frac{\bar{g}_2\bar{v}}{2c_{\bar{\theta}}} \qquad G_f = \frac{1}{\sqrt{2}\bar{v}^2}$$

$$\rightarrow$$

$$\hat{v}^2 = \frac{1}{\sqrt{2}G_f}$$

$$\sin\hat{\theta}^2 = \frac{1}{2}\left(1-\sqrt{1-\frac{4\pi\alpha_{\rm em}}{\sqrt{2}G_f m_Z^2}}\right)$$

$$\hat{g}_1 = \frac{\sqrt{4\pi\alpha_{\rm em}}}{\cos\hat{\theta}}$$

$$\hat{g}_2 = \frac{\sqrt{4\pi\alpha_{\rm em}}}{\sin\hat{\theta}}$$

in the SM at tree-level $\bar{\kappa} = \hat{\kappa}$

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The values can be inferred from the measurements e.g. of $\{\alpha_{\rm em}, m_Z, G_f\}$:

$$\begin{aligned}
\alpha_{\rm em} &= \frac{\bar{g}_1\bar{g}_2}{\bar{g}_1^2+\bar{g}_2^2}\left[1+\bar{v}^2 C_{HWB}\frac{\bar{g}_2^3/\bar{g}_1}{\bar{g}_1^2+\bar{g}_2^2}\right]\\
m_Z &= \frac{\bar{g}_2\bar{v}}{2c_{\bar{\theta}}}+\delta m_Z(C_i)\\
G_f &= \frac{1}{\sqrt{2}\bar{v}^2}+\delta G_f(C_i)
\end{aligned}
\quad\rightarrow\quad
\begin{aligned}
\hat{v}^2 &= \frac{1}{\sqrt{2}G_f}\\
\sin\hat{\theta}^2 &= \frac{1}{2}\left(1-\sqrt{1-\frac{4\pi\alpha_{\rm em}}{\sqrt{2}G_f m_Z^2}}\right)\\
\hat{g}_1 &= \frac{\sqrt{4\pi\alpha_{\rm em}}}{\cos\hat{\theta}}\\
\hat{g}_2 &= \frac{\sqrt{4\pi\alpha_{\rm em}}}{\sin\hat{\theta}}
\end{aligned}$$

in the SM at tree-level $\bar{\kappa} = \hat{\kappa}$

in the SMEFT $\bar{\kappa} = \hat{\kappa} + \delta\kappa(C_i)$

More in detail: parameter shifts from input choice

To have numerical predictions it is necessary to replace $\bar{\kappa} \to \hat{\kappa} + \delta\kappa(C_i)$ for all the parameters in the Lagrangian.

$\{\alpha_{\rm em}, m_Z, G_f\}$ scheme

$$\delta m_Z^2 = m_Z^2 \hat{v}^2 \left(\frac{c_{HD}}{2} + 2c_{\hat\theta} s_{\hat\theta} c_{HWB}\right)$$

$$\delta G_f = \frac{\hat{v}^2}{\sqrt{2}} \left((c_{Hl}^{(3)})_{11} + (c_{Hl}^{(3)})_{22} - (c_{ll})_{1221}\right)$$

$$\delta g_1 = \frac{s_{\hat\theta}^2}{2(1-2s_{\hat\theta}^2)} \left(\sqrt{2}\delta G_f + \delta m_Z^2/m_Z^2 + 2\frac{c_{\hat\theta}^3}{s_{\hat\theta}} c_{HWB} \hat{v}^2\right)$$

$$\delta g_2 = -\frac{c_{\hat\theta}^2}{2(1-2s_{\hat\theta}^2)} \left(\sqrt{2}\delta G_f + \delta m_Z^2/m_Z^2 + 2\frac{s_{\hat\theta}^3}{c_{\hat\theta}} c_{HWB} \hat{v}^2\right)$$

$$\delta s_\theta^2 = 2c_{\hat\theta}^2 s_{\hat\theta}^2 (\delta g_1 - \delta g_2) + c_{\hat\theta} s_{\hat\theta}(1-2s_{\hat\theta}^2) c_{HWB} \hat{v}^2$$

$$\delta m_h^2 = m_h^2 \hat{v}^2 \left(2c_{H\square} - \frac{c_{HD}}{2} - \frac{3c_H}{2lam}\right)$$

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To have numerical predictions it is necessary to replace $\bar{\kappa} \to \hat{\kappa} + \delta\kappa(C_i)$ for all the parameters in the Lagrangian.

$\{m_W, m_Z, G_f\}$ scheme

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$$\delta g_1 = -\frac{1}{2} \left(\sqrt{2}\delta G_f + \frac{1}{s_{\hat\theta}^2} \frac{\delta m_Z^2}{m_Z^2} \right)$$

$$\delta g_2 = -\frac{1}{\sqrt{2}} \delta G_f$$

$$\delta s_\theta^2 = 2 c_{\hat\theta}^2 s_{\hat\theta}^2 (\delta g_1 - \delta g_2) + c_{\hat\theta} s_{\hat\theta} (1 - 2 s_{\hat\theta}^2) c_{HWB} \hat{v}^2$$

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$$\delta m_h^2 = m_h^2 \hat{v}^2 \left(2c_{H\square} - \frac{c_{HD}}{2} - \frac{3c_H}{2lam}\right)$$

the redefinitions $\bar{\kappa} \to \hat{\kappa} + \delta\kappa$ are performed automatically in the Lagrangian (both schemes)

Numerical inputs chosen

Input parameters	Value	Ref.	
$\hat{\alpha}_{ew}(m_Z)$		$1/127.950$	PDG 2016, 1203.5425
$\hat{m}_W$	GeV	80.365 ± 0.016	TeVatron: 1307.7627
$\hat{m}_Z$	GeV	91.1876 ± 0.0021	PDG 2016, hep-ex/0509008,1203.5425
$\hat{G}_F$	GeV^{-2}	$1.1663787(6) \times 10^{-5}$	PDG 2016, 1203.5425
$\hat{m}_h$	GeV	$125.09 \pm 0.21 \pm 0.11$	1503.07589
$\hat{\alpha}_s(m_Z)$	GeV	0.1185 ± 0.0011	PDG 2016
$\hat{m}_e$	GeV	$0.5109989461(31) \times 10^{-3}$	PDG 2016
$\hat{m}_\mu$	GeV	$105.6583745(24) \times 10^{-3}$	PDG 2016
$\hat{m}_\tau$	GeV	1.77686 ± 0.00012	PDG 2016
$\hat{m}_u$	GeV	$2.2^{+0.6}_{-0.4} \times 10^{-3}$	PDG 2016
$\hat{m}_c$	GeV	1.28 ± 0.03	PDG 2016
$\hat{m}_t$	GeV	$173.21 \pm 0.51 \pm 0.71$	PDG 2016
$\hat{m}_d$	GeV	$4.7^{+0.5}_{-0.4} \times 10^{-3}$	PDG 2016
$\hat{m}_s$	GeV	$0.096^{+0.008}_{-0.004}$	PDG 2016
$\hat{m}_b$	GeV	$4.18^{+0.04}_{-0.03}$	PDG 2016
CKM: λ		0.22506	PDG 2016
A		0.811	PDG 2016
ρ		0.124	PDG 2016
η		0.356	PDG 2016

Implemented frameworks

We implemented 6 different frameworks:

3 flavor structures: general; $U(3)^5$ symmetric; linear MFV

$\times$

2 input schemes: $\hat{\alpha}_{\rm em}, \hat{m}_Z, \hat{G}_f$; $\hat{m}_W, \hat{m}_Z, \hat{G}_f$

Implemented frameworks

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3	flavor structures	general $U(3)^5$ symmetric linear MFV	$\times$	2	input schemes	$\hat{\alpha}_{\rm em}, \hat{m}_Z, \hat{G}_f$ $\hat{m}_W, \hat{m}_Z, \hat{G}_f$

completely general flavor indices:

2499 parameters including all complex phases

Implemented frameworks

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---

assume an **exact flavor symmetry**

$$U(3)^5 = U(3)_q \times U(3)_u \times U(3)_d \times U(3)_l \times U(3)_e$$

under which: $\psi \mapsto U_\psi \psi$ for $\psi = \{u, d, q, l, e\}$

- The Yukawas are the only **spurions** breaking the symmetry:

$$Y_u \mapsto U_u Y_u U_q^\dagger \qquad Y_d \mapsto U_d Y_d U_q^\dagger \qquad Y_l \mapsto U_e Y_l U_l^\dagger \,.$$

- flavor indices contractions are fixed by the symmetry → less parameters

Examples:

$$\mathcal{Q}_{Hu} = (H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{u}_r \gamma^\mu u_s)\, \delta_{rs}$$

$$\mathcal{Q}_{eB} = B_{\mu\nu}(\bar{l}_r H \sigma^{\mu\nu} e_s)\, (\mathbf{Y_l})_{rs}$$

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---

assume $U(3)^5$ symmetry + CKM only source of ~~CP~~

- all Wilson coefficients $\in \mathbb{R}$
- CP odd bosonic operators are absent ($\propto J_{CP} \simeq 10^{-5}$)
- includes the first order in flavor violation expansion. E.g.:

$$\mathcal{Q}_{Hu} = (H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{u}_r \gamma^\mu u_s) \left[\mathbb{1} + (\mathbf{Y_u Y_u^\dagger})\right]_{rs}$$

$$\mathcal{Q}_{Hq}^{(1)} = (H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{q}_r \gamma^\mu q_s) \left[\mathbb{1} + (\mathbf{Y_u^\dagger Y_u}) + (\mathbf{Y_d^\dagger Y_d})\right]_{rs}$$

$$\hookrightarrow \bar{u}_L \gamma^\mu \left[\mathbb{1} + Y_u^\dagger Y_u + V_{\rm CKM} Y_d^\dagger Y_d V_{\rm CKM}^\dagger\right] u_L$$

$$+ \bar{d}_L \gamma^\mu \left[\mathbb{1} + V_{\rm CKM}^\dagger Y_u^\dagger Y_u V_{\rm CKM} + Y_d^\dagger Y_d\right] d_L$$

SMEFTsim: basic structure and main features

2 independent, equivalent models sets: best for debugging and validation

each contains: 6 pre-exported UFO models + FeynRules sources

Main characteristics:

- contain SM + SM radiative Higgs couplings (hgg, $h\gamma\gamma$, $hZ\gamma$) + complete Warsaw basis for 3 generations
- canonical kinetic terms + input shifts automatically implemented
- restrictions available for massless fermions ($\neq t, b$) + CP conserving
- only unitary gauge: ghost Lagrangian not adjusted for $d = 6$ effects
- only tree level calculations in MadGraph5
- by construction: theoretical uncertainty of order % (neglected $d = 8$, radiative corrections etc)

Possible application: a pole observables program

The most general SMEFT setup has too many parameters!

How to reduce them?

- IR assumptions (symmetries: CP, flavor)
- smart choice of observables + phase space

Basic idea: the dominant effects are interference terms between the SM and $d = 6$ contributions

$\downarrow$

close to the narrow SM bosons resonances (Z, W, h)
the pole structure can enhance/suppress the impact of certain operators

...+ less trouble with EFT validity in this phase space

Possible application: a pole observables program

– Close to a narrow resonance peak –

Relevant terms

- non-SM corrections to SM interactions $\sim \langle H^\dagger | \mathcal{L}_{\rm SM} | H \rangle$
- non-SM corrections to SM interactions $\sim \partial$
- corrections to propagators: δm_W

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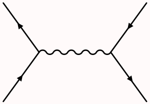
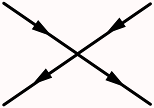
Suppressed terms

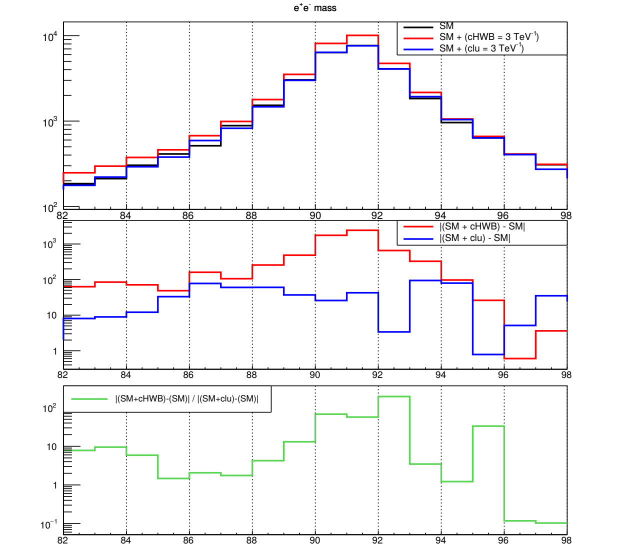
- most ψ^4 operators: give diagrams with less resonances

In general: expected to be suppressed wrt. "pole operators" by

$$\left(\frac{\Gamma_B m_B}{v^2}\right)^n \text{ or } \left(\frac{\Gamma_B m_B}{\mathcal{I}}\right)^n, \qquad B = \{Z, W, h\}, \quad \mathcal{I} \sim s, \quad n = \begin{array}{l}\#\text{ missing}\\ \text{resonances}\end{array}$$

Example: Drell-Yan via Z resonance  vs. 

Possible application: a pole observables program



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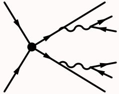
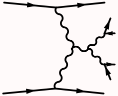
! Not *always* the case. E.g. VBS  vs 

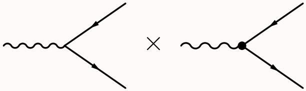
the 4-fermion diagram is <u>not</u> removed by poles selection.
Other kinematic variables may help? ▸ can be checked with MG

Other possible selection criteria

The SM – ($d = 6$) interference can also be suppressed by:

- proportionality to light fermion masses.

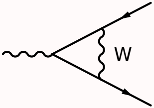
  Example: dipole operators can be neglected for $f \neq t, b$

  $\sim m_f$

- flavor violation in neutral currents can also be neglected

  The SM amplitude is very suppressed:

  $$\sim \frac{m_j^2 V_{jk}^* V ji}{32\pi^2 m_W^2}$$

  (similar suppression for Higgs vertex)

- ...

Summary

A sensible reduction of the # of parameters:

Case	total # par.	par. for $W/Z/h$ pole obs.
general	2499	~ 84
$U(3)^5$ symmetric	~ 80	~ 37
MFV	~ 90	~ 30

Takeaway message on poles program

- poles are an interesting (and safe!) place to look into.
  They can give relevant information, complementary to that in the tails.
- the pole structure selects a small number of parameters
  compared to the complete set (even in the flavor general case).
- the SMEFTsim package can help to develop a consistent poles program!

Backup slides

The Warsaw basis

Gzadkowski,Iskrzynski,Misiak,Rosiek 1008.4884

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC}G_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK}W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star\left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I\varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\, \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{\varphi}\, G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{e}_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\, \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{\varphi}\, W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{q}_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{\varphi}\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I\varphi)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\, \widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)\varphi\, G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W_{\mu\nu}^I B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{d}_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}_p\gamma^\mu d_r)$

The Warsaw basis

Gzadkowski,Iskrzynski,Misiak,Rosiek 1008.4884

$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\varepsilon_{jk}(\bar{q}_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\varepsilon_{jk}(\bar{q}_s^k T^A d_t)$	$Q_{qqq}^{(1)}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\varepsilon_{jk}(\bar{q}_s^k u_t)$	$Q_{qqq}^{(3)}$	$\varepsilon^{\alpha\beta\gamma}(\tau^I\varepsilon)_{jk}(\tau^I\varepsilon)_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j\sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu} u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$