An EFT approach to possible lepton anomalies

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Coy and Frigerio *in preparation*

Leptonic physics and EFTs

- Extensive past, present, and future experimental programmes testing copious lepton sector observables
  - Precision era for neutrino physics
  - $(g-2)_\mu$ anomaly now $\gtrsim 3.5\sigma$, could reach 5σ at Fermilab
  - Various hints of LFUV in $b \to s\ell^+\ell^-$ and $b \to c\ell\nu$ channels
  - Stringent limits on CLFV: $BR(\mu \to e\gamma) \lesssim 10^{-13}$, $BR(\tau \to \mu\gamma, e\gamma) \lesssim 10^{-8}$, weaker constraints on $Z, h \to \ell_a^\pm \ell_b^\mp$
- EFT a useful framework for consistently taking many constraints into account
- Used as model-independent approach or to study specific model
- In EFT description, correlations between different observables appear independently of UV details of model

EFT of type-I seesaw

- Add n_s right-handed fermion singlets, Lagrangian is

$$\mathcal{L} = \mathcal{L}_{SM} + \overline{\nu_{Ri}} i \partial\!\!\!/ \nu_{Ri} - Y_{\nu,ia} \overline{\nu_{Ri}} \tilde{H}^\dagger l_{La} - \frac{1}{2} \overline{\nu_{Ri}} M_{ij} \nu^c_{Rj} + h.c. \quad (1)$$

- Aim: find all leading order WCs, compare different observables
- Analysis is independent of textures, additional symmetries etc.
- Integrating out heavy ν_R at tree-level gives[1]

$$\mathcal{L}_{tree} = \frac{(Y_\nu^T M^{-1} Y_\nu)_{ab}}{2} Q_{W,ab} + \frac{(Y_\nu^\dagger M^{*-1} M^{-1} Y_\nu)_{ab}}{4} \left(Q^{(1)}_{Hl,ab} - Q^{(3)}_{Hl,ab} \right) + h.c.$$

- Normal procedure of matching at tree-level, running at 1-loop
  - Systematically selects leading logarithms
  - Use RGEs[2], including mixing $C_W^2 \to C^{d=6}$ [3]

[1] Broncano et al. Phys. Lett. B **552** (2003) 177-184

[2] Jenkins et al. JHEP **1310** (2013) 087, **1401** (2014) 035, **1404** (2014) 159

[3] Broncano et al. Nucl. Phys. B **705** (2005) 269-295, Davidson et al. 1807.04283

Some preliminary results

- Calculate observables at leading log, e.g.

$$\Gamma(Z \to \ell_k^+ \ell_m^-) \approx \frac{v^2 m_Z^3}{6(4\pi)^5} \left(\frac{17 g_2^2 + g_1^2}{12} \right)^2 \left[Y_\nu^\dagger M^{*-1} M^{-1} \log\left(\frac{|M|}{m_W} \right) Y_\nu \right]_{km}^2$$

- Previously calculated in specific models[4], but EFT computationally simple to derive, easily applicable to variations of type-I seesaw
- Correlations between observables, e.g.

$$\frac{BR(h \to e^\pm \mu^\mp)}{BR(Z \to e^\pm \mu^\mp)} = 2.8 \times 10^{-4}; \quad \frac{BR(Z \to e^\pm \mu^\mp)}{BR(\mu^\mp \to e^\mp e^+ e^-)} = 1.58.$$

- Predict much stronger bounds on CLFV h, Z decays
- Bottom-up approach using spurions enables us to predict structure of WCs for seesaw and other models, *work in progress*

[4] e.g. Illana and Riemann, Phys. Rev. D **63** (2001) 053004, Herrero et al. 1807.01698

EFT procedure: 1-loop matching

- 1-loop matching required to find leading-order WCs not induced by operator mixing

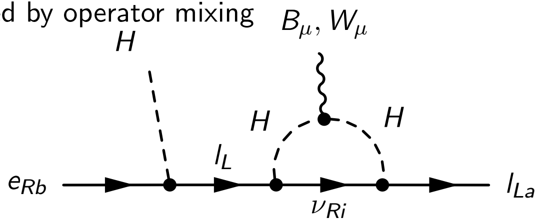

Figure 1: 1-loop matching to calculate C_{eB}, C_{eW} in seesaw EFT.

- Combining 1-loop matching at $\mu = \Lambda$ (Fig. 1) and 1-loop matching at $\mu = m_W$, find $\mathcal{L} \supset \frac{C_{e\gamma,ab}}{\Lambda^2}\mathcal{O}_{e\gamma,ab}$ with

$$\frac{C_{e\gamma,ab}}{\Lambda^2} = -\frac{ev}{\sqrt{2}}\frac{(Y_\nu^\dagger M^{*-1} M^{-1} Y_\nu Y_e)_{ab}}{96\pi^2} - \frac{eg^2 U^*_{ai} m_i^2 U_{bi} m_b}{256\pi^2 m_W^4}. \quad (2)$$

- See that $\Delta a_f \propto \text{Re}[C_{e\gamma,ff}] < 0$, $d_f \propto \text{Im}[C_{e\gamma,ff}] = 0$, can calculate $\Gamma(\ell_a^\pm \to \ell_b^\pm \gamma)$

The next steps

Ongoing/future work:

- Further comparisons with literature for various observables
- Comparison between correlations in type-I seesaw and in other neutrino mass models through spurion analysis
- EFT analysis of $b \to s$ anomalies at tree-level and 1-loop

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Back-up slides

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Renormalisation Group Equations

- Evolution of Wilson coefficients with scale μ governed by RGEs,

$$\frac{dC_i}{d\log\mu} = \gamma_{ij} C_j, \tag{3}$$

where γ_{ij} is matrix of anomalous dimensions computed for $d = 6$ SMEFT cite JMT

- Initial conditions imposed by tree-level matching, specifically

$$\frac{C_{W,ab}(\Lambda)}{\Lambda} = \frac{\left(Y_\nu^T M^{-1} Y_\nu\right)_{ab}}{2}; \quad \frac{C^{(1)}_{Hl,ab}(\Lambda)}{\Lambda^2} = -\frac{C^{(3)}_{Hl,ab}(\Lambda)}{\Lambda^2} = \frac{\left(Y_\nu^\dagger M^{*-1} M^{-1} Y_\nu\right)_{ab}}{4}$$

with all other $C_i(\Lambda) = 0$. Example RGE is

$$\begin{aligned}
\frac{16\pi^2}{\Lambda^2}\frac{dC_{eH,ab}}{d\log\mu} &= 4\lambda\left(C^{(1)}_{Hl} Y_e + 3C^{(3)}_{Hl} Y_e\right)_{ab} + 2\left(C^{(1)}_{Hl} Y_e Y_e^\dagger Y_e\right)_{ab} \\
&- 4\mathrm{Tr}\left[C^{(3)}_{Hl} Y_e Y_e^\dagger\right](Y_e)_{ab} - 6g_1^2\left(C^{(1)}_{Hl} Y_e\right)_{ab} - 6g_1^2\left(C^{(3)}_{Hl} Y_e\right)_{ab} \\
&+ \frac{4}{3} g_2^2 (Y_e)_{ab}\,\mathrm{Tr}[C^{(3)}_{Hl}] + \frac{7}{4}\left(C_W^\dagger C_W Y_e\right)_{ab} - \mathrm{Tr}\left[C_W^\dagger C_W\right](Y_e)_{ab}\,.
\end{aligned}$$

Mixing C_W^2 into $C^{d=6}$

- As well as $C_i^{d=6} \to C_j^{d=6}$ mixing, have $C_W^2 \to C^{d=6}$, e.g.

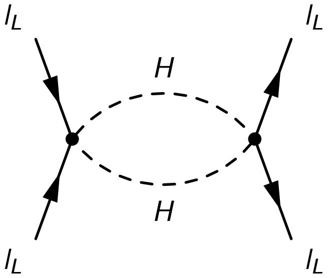
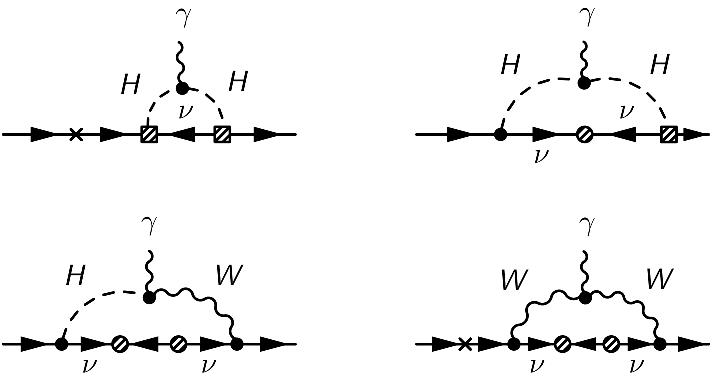


Figure 2: 1-loop mixing of C_W^2 into C_{ll}.

- This contributes to the RGE of C_{ll} as (check!)

$$\frac{16\pi^2}{\Lambda^2}\frac{dC_{ll,abcd}}{d\log\mu} = -2C^{\dagger}_{W,ac}C_{W,bd} + C^{d=6} \text{ terms} \qquad (4)$$

One-loop matching at m_W



- Integrate out gauge bosons
- Generates contribution to dipole operator of size

$$\mathcal{L} \supset -\frac{eg^2 U_{ai}^* m_i^2 U_{bi}}{256\pi^2 m_W^4}(\overline{e_a}\sigma_{\mu\nu}(m_a P_L + m_b P_R)e_b)F^{\mu\nu} \qquad (5)$$