Non-Standard Light- (Quark) Yukawas and the Higgs Portal

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Based on: FB, J. Brod, P. Uttarayat, & J. Zupan [arXiv:1504.04022]

Motivation

- Fits to Higgs data allows large deviations from SM light-quark Yukawa couplings.
- However, it is difficult to realize such large deviations in concrete models.
- This motivates a survey of models with modified Yukawas.
- On the other hand, in Higgs portal DM models, direct detection rates are sensitive to the light-quark Yukawa couplings $\rightarrow$ a useful probe.

Global fit to the Higgs data

- Allowing one light-Yukawa to float at a time gives
  Kagan, Perez, Petriello, Soreq, Stoynev, and Zupan [arXiv:1406.1722]

$$
\begin{aligned}
|\kappa_u| &< 0.98 m_b/m_u \\
|\kappa_d| &< 0.93 m_b/m_d \\
|\kappa_s| &< 0.70 m_b/m_s
\end{aligned}
$$

- However, such large values are not likely to be obtained in a complete model.

- Modified Yukawa couplings are interesting because, e.g.: DM, dipole moms., etc.

Framework

- In the SM, $y_f = \sqrt{2} m_f / v_W$ but in general could have

$$\mathcal{L}_{\rm eff,q} = \overbrace{\underbrace{-\kappa_q \frac{m_q}{v_W}\bar{q}qh}_{\text{CP Conserving}} \underbrace{- i\tilde{\kappa}_q \frac{m_q}{v_W}\bar{q}\gamma_5 qh}_{\text{CP Violating}}}^{\text{Flavor Diagonal}} - \overbrace{\Big[\underbrace{\left(\kappa_{qq'} + i\tilde{\kappa}_{qq'}\right)}_{\substack{\Re\,:\,\text{CPC} \\ \Im\,:\,\text{CPV}}} \bar{q}_L q'_R h + \text{h.c.} \Big]}^{\text{Flavor Violating}}$$

where, in the SM, $\kappa_q = 1$ while $\tilde{\kappa}_q = \kappa_{qq'} = \tilde{\kappa}_{qq'} = 0$.

- Lepton Yukawas were considered in, e.g.,
Dery, Efrati, Nir, Soreq, & Susič [arXiv:1408.1371]; Dery, Efrati, Hiller, Hochberg, & Nir [arXiv:1304.6727]; Dery, Efrati, Hochberg, & Nir [arXiv:1302.3229]

Down-type flavor-diagonal Yukawas in a selection of models

Model	κ_b	$\kappa_{s(d)}/\kappa_b$	$\tilde{\kappa}_b/\kappa_b$	$\tilde{\kappa}_{s(d)}/\kappa_b$
SM	1	1	0	0
NFC	$V_{hd}\, v_W/v_d$	1	0	0
MSSM	$-\sin\alpha/\cos\beta$	1	0	0
GL	$\simeq 3$	$\simeq 5/3(7/3)$	$\mathcal{O}(1)$	$\mathcal{O}(\kappa_{s(d)}/\kappa_b)$
GL2	$-\sin\alpha/\cos\beta$	$\simeq 3(5)$	$\mathcal{O}(\epsilon^2)$	$\mathcal{O}(\kappa_{s(d)}/\kappa_b)$
MFV	$1+\frac{\mathrm{Re}(a_d v_W^2+2c_d m_t^2)}{\Lambda^2}$	$1-\frac{2\mathrm{Re}(c_d)m_t^2}{\Lambda^2}$	$\frac{\Im(a_d v_W^2+2c_d m_t^2)}{\Lambda^2}$	$\frac{\Im(a_d v_W^2+2c_d \lvert V_{ts(td)}\rvert^2 m_t^2)}{\Lambda^2}$
RS	$1-\mathcal{O}\left(\frac{v_W^2}{m_{KK}^2}\bar{Y}^2\right)$	$1+\mathcal{O}\left(\frac{v_W^2}{m_{KK}^2}\bar{Y}^2\right)$	$1+\mathcal{O}\left(\frac{v_W^2}{m_{KK}^2}\bar{Y}^2\right)$	$1+\mathcal{O}\left(\frac{v_W^2}{m_{KK}^2}\bar{Y}^2\right)$
pNGB	$1+\mathcal{O}\left(\frac{v_W^2}{f^2}\right)+\mathcal{O}\left(y_*^2\lambda^2\frac{v_W^2}{M_*^2}\right)$	$1+\mathcal{O}\left(y_*^2\lambda^2\frac{v_W^2}{M_*^2}\right)$	$\mathcal{O}\left(y_*^2\lambda^2\frac{v_W^2}{M_*^2}\right)$	$\mathcal{O}\left(y_*^2\lambda^2\frac{v_W^2}{M_*^2}\right)$

Up-type flavor-diagonal Yukawas in a selection of models

Model	κ_t	$\kappa_{c(u)}/\kappa_t$	$\tilde{\kappa}_t/\kappa_t$	$\tilde{\kappa}_{c(u)}/\kappa_t$
SM	1	1	0	0
NFC	$V_{hu}\, v_W/v_u$	1	0	0
MSSM	$\cos\alpha/\sin\beta$	1	0	0
GL	$1+\mathcal{O}(\epsilon^2)$	$\simeq 3(7)$	$\mathcal{O}(\epsilon^2)$	$\mathcal{O}(\kappa_{c(u)})$
GL2[1]	$\cos\alpha/\sin\beta$	$\simeq 3(7)$	$\mathcal{O}(\epsilon^2)$	$\mathcal{O}(\kappa_{c(u)})$
MFV	$1+\frac{\mathrm{Re}(a_u v_W^2+2b_u m_t^2)}{\Lambda^2}$	$1-\frac{2\mathrm{Re}(b_u)m_t^2}{\Lambda^2}$	$\frac{\Im(a_u v_W^2+2b_u m_t^2)}{\Lambda^2}$	$\frac{\Im(a_u v_W^2)}{\Lambda^2}$
RS	$1-\mathcal{O}\left(\frac{v_W^2}{m_{KK}^2}\bar{Y}^2\right)$	$1+\mathcal{O}\left(\frac{v_W^2}{m_{KK}^2}\bar{Y}^2\right)$	$1+\mathcal{O}\left(\frac{v_W^2}{m_{KK}^2}\bar{Y}^2\right)$	$1+\mathcal{O}\left(\frac{v_W^2}{m_{KK}^2}\bar{Y}^2\right)$
pNGB	$1+\mathcal{O}\left(\frac{v_W^2}{f^2}\right)+\mathcal{O}\left(y_*^2\lambda^2\frac{v_W^2}{M_*^2}\right)$	$1+\mathcal{O}\left(y_*^2\lambda^2\frac{v_W^2}{M_*^2}\right)$	$\mathcal{O}\left(y_*^2\lambda^2\frac{v_W^2}{M_*^2}\right)$	$\mathcal{O}\left(y_*^2\lambda^2\frac{v_W^2}{M_*^2}\right)$

[1] For a detailed study of this model see: Bauer, Carena, & Gemmler[arXiv:1506.01719]

Higgs portal DM

- The Higgs portal interaction Laqrangian is

$$\mathcal{L}_\chi = \begin{cases} g_\chi \chi^\dagger \chi H^\dagger H\,, & \text{scalar DM;} \\ g_\chi \frac{1}{\Lambda}\bar{\chi}\chi H^\dagger H + i\tilde{g}_\chi \frac{1}{\Lambda}\bar{\chi}\gamma_5\chi H^\dagger H\,, & \text{fermion DM;} \\ \frac{g_\chi}{2}\chi^\mu \chi_\mu H^\dagger H, & \text{vector DM.} \end{cases}$$

- After EWSB, the $H^\dagger H$ operator gives

$$H^\dagger H = \frac{1}{2}(v_W^2 + 2v_W h + h^2),$$

Sensitivity of direct detection to light Yukawas

- Low energy effective Lag.

$$\mathcal{L} \supset g_\chi \frac{v_W}{m_h^2} \chi^\dagger \chi \, \mathcal{S}_q$$

- Scalar current

$$\mathcal{S}_q = \sum_{q \in \{u,d,s\}} \frac{m_q}{v_W} \bar{q} q - \mathcal{C}_g \frac{\alpha_s}{12\pi v_W} G^a_{\mu\nu} G^{a\mu\nu} + \text{CP odd}$$

- Effective coupling to nucleons is given by $f_{\mathcal{S}}^{(N)} \equiv \langle N | \mathcal{S}_q | N \rangle$

- Finally,

$$f_{\mathcal{S}}^{(p)} = \frac{m_W}{v_W} \left[1.8\kappa_u + 3.4\kappa_d + 4.3\kappa_s + 6.7(\kappa_c + \kappa_b + \kappa_t) \right] \times 10^{-2}$$

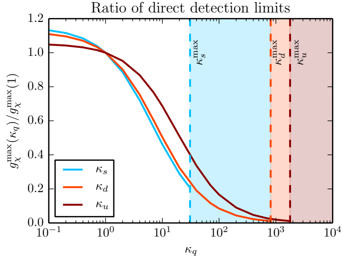
$$f_{\mathcal{S}}^{(n)} = \frac{m_W}{v_W} \left[1.6\kappa_u + 3.8\kappa_d + 4.3\kappa_s + 6.7(\kappa_c + \kappa_b + \kappa_t) \right] \times 10^{-2}$$

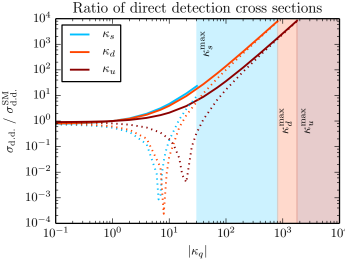
Sensitivity of direct detection to light Yukawas – results

- The direct detection cross-section

$$\sigma_{\text{d.d.}} \propto \left[Z\, f_{\mathcal{S}}^{(p)} + (A - Z)\, f_{\mathcal{S}}^{(n)} \right]^2$$

where A is the mass number and Z is the atomic number of the nucleus





- N.B.: for a much more realistic way to probe light-quark Yukawa see Frank Petriello's talk from yesterday [arXiv:1406.1722].

Summary

- ▷ Higgs data is compatible with large deviations in light quark Yukawa couplings.
- ▷ However, such large deviations are difficult to realize in complete models.
- ▷ The expected deviations in a selection of models was presented.
- ▷ On a more speculative note, direct detection of Higgs portal DM might give a handle on light quark Yukawas.