Stability of the Higgs sector in a flavour-inspired multi-scale model

(based on 2011.01946 with G. Isidori and A. E. Thomsen)

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Introduction

- Strong constraints on generic flavour-violating new physics: $\Lambda \gtrsim 10^4$ TeV
- TeV-scale NP, as suggested by the B-anomalies, needs to be coupled non-universally [see Cornella et al., 2103.16558]
- Generate the SM flavour structure from a hierarchy of NP scales $\longrightarrow$ 3-site model: non-universal gauge interactions

  [see Panico and Pomarol, 1603.06609, Bordone et al., 1712.01368]
- Largest mass scale is $\sim 10^3$ TeV

What about the hierarchy problem?

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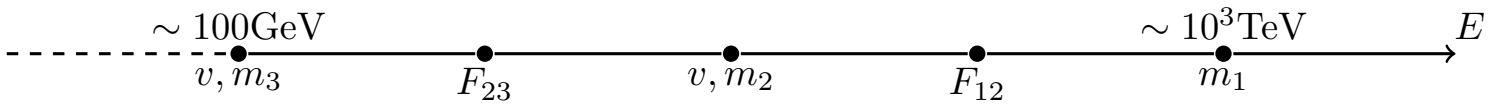
The model

Simplified model with a $\mathrm{SU}(2)_1 \times \mathrm{SU}(2)_2 \times \mathrm{SU}(2)_3$ gauge symmetry:

The link fields $\Omega_{i(i+1)}$ mediate the interaction between the different sites:

$$\mathcal{L} \supset \kappa_{i(i+1)}\, F_{i(i+1)} H_i^\dagger \Omega_{i(i+1)} H_{i+1} \;+\; \text{H.c.}$$
$$- \lambda_i^-\, H_i^\dagger \Omega^\dagger_{(i-1)i} \Omega_{(i-1)i} H_i$$
$$- x_{i(i+1)} \overline{Q}_{L,i} \Omega_{i(i+1)} Q_{R,i+1}$$

Fields	SO(1,3)	$[\mathrm{SU}(2)]^2$
q_i	$(\frac{1}{2},0)$	$\mathbf{2}_i$
Q_i	$(\frac{1}{2},0) \oplus (0,\frac{1}{2})$	$\mathbf{2}_i$
$u_i,\ d_i$	$(0,\frac{1}{2})$	$\mathbf{1}$
H_i	0	$\mathbf{2}_i$
$\Omega_{i(i+1)}$	0	$\mathbf{2}_i \otimes \bar{\mathbf{2}}_{i+1}$

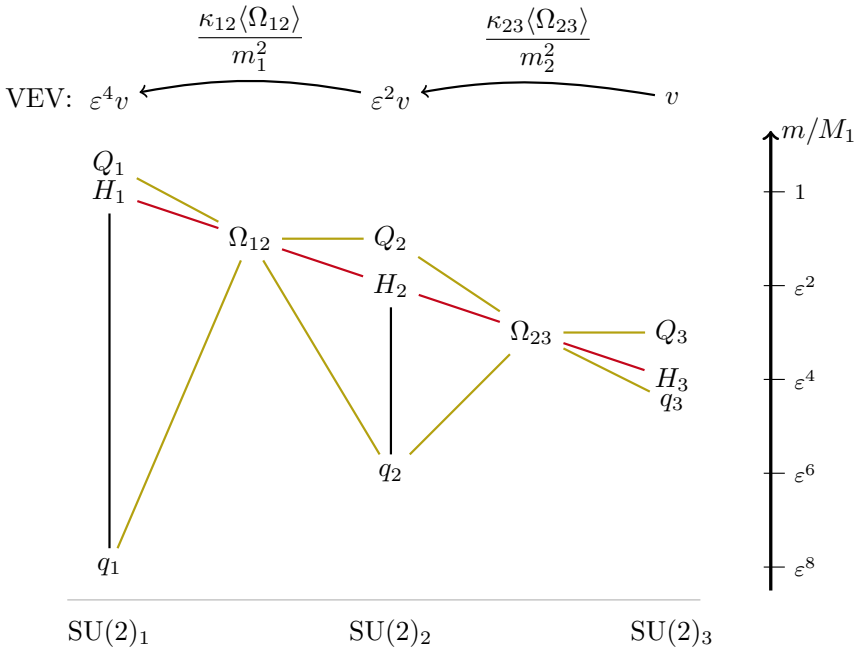


Hierarchies expressed in terms of an order parameter

$$\varepsilon \sim 10^{-1} \sim (4\pi)^{-1}$$

.

Fermion masses and mixings



[Figure by A. E. Thomsen]

After SSB, the VEV v propagates to the other two sites, generating the mass hierarchy:

$$\langle H_3 \rangle = \begin{pmatrix} 0 \\ v_{\rm EW} \end{pmatrix}$$

$$\langle H_1 \rangle \sim \varepsilon^4 \begin{pmatrix} 0 \\ v_{\rm EW} \end{pmatrix}, \qquad \langle H_2 \rangle \sim \varepsilon^2 \begin{pmatrix} 0 \\ v_{\rm EW} \end{pmatrix},$$

$$\rightarrow m^u_{ij} \sim \mathrm{diag}(\varepsilon^4,\ \varepsilon^2,\ 1)\, v_{\rm EW}$$

VL fermions generate the mixing:

$$V_{CKM} \sim \begin{pmatrix} 1 & \theta_{12} & \theta_{12}\theta_{23} \\ & 1 & \theta_{23} \\ & & 1 \end{pmatrix}$$

$$\theta_{12} = \frac{x_{12}\langle\Omega_{12}\rangle}{M_2} f_{12}(y_i, \hat{y}_i) \sim \varepsilon$$
$$\theta_{23} = \frac{x_{23}\langle\Omega_{23}\rangle}{M_3} f_{23}(y_i, \hat{y}_i) \sim \varepsilon$$

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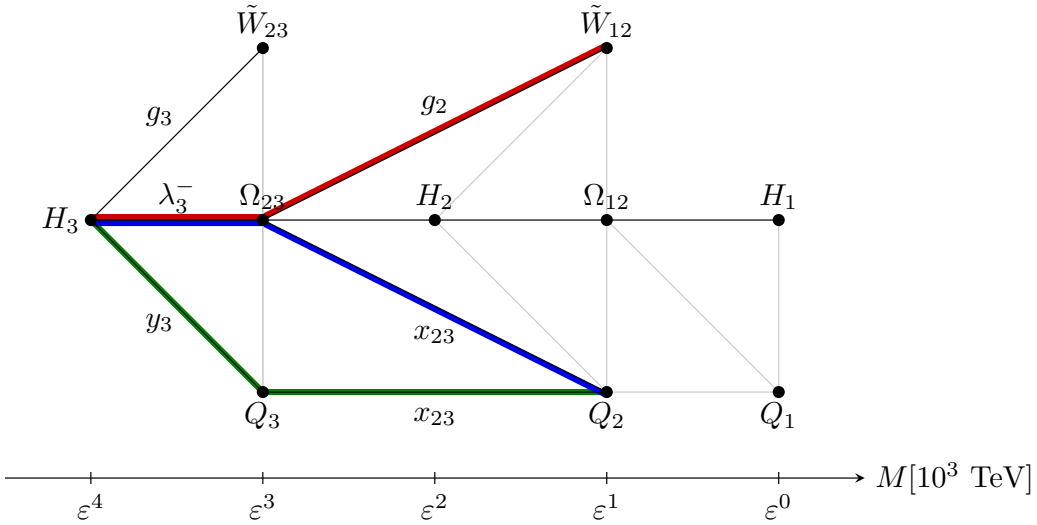
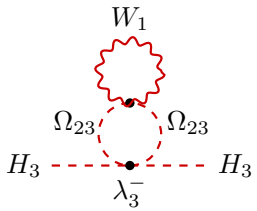
Stability of the Higgs mass

Radiative corrections are proportional to all NP scales:

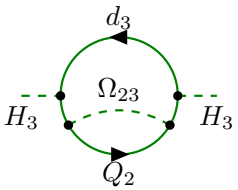
$$\delta m_3^2 \propto M_{NP}^2 \sim \frac{m_3^2}{\varepsilon^8}$$

$\longrightarrow$ need suppression from loops+couplings





$$\longrightarrow \delta m_3^2 \sim \frac{\lambda_3^-}{\varepsilon^2} m_3^2$$



$$\longrightarrow \delta m_3^2 \sim \frac{x_{23}^2}{\varepsilon^2} m_3^2$$

$\rightarrow \lambda_i^- \sim \varepsilon^2 \qquad x_{ij} \sim \varepsilon$

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Conclusion

- We have shown a toy model that links scale hierarchies with flavour hierarchies
- The SM pattern of masses and mixings can be reproduced introducing VL fermions
- The SM Higgs mass is protected by the multi-site structure provided that:
  - Scalar quartic couplings are small: $\lambda_i^- \sim 1\%$
    $\rightarrow$ *little hierarchy*
  - Fermion-link field interactions are suppressed: $x_{ij} \sim 10\ \%$
    $\rightarrow$ needed also for fermion hierarchy

Thank you!

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