מכון ויצמן למדע
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TOP FLAVOR VIOLATING DECAYS

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A. Azatov, G. Panico, G. Perez and YS - arXiv:1408.4525

A. Dery, A. Efrati, Y. Nir, YS and V. Susic - arXiv:1408.1371

OUTLINE

- Introduction and motivation
- Top-flavor violation in composite Higgs models
- Top Higgs flavor violation
- Summary

INTRODUCTION

Standard Model:

- diagonal Higgs Yukawa
- universal Z couplings

⇒ $t \to qh$ and $t \to qZ$ are **highly suppressed**

Experimentally promising channels

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Current bounds:
(at 95%CL)

$$\mathrm{BR}(t \to qh) < 0.56\%$$ CMS, ATLAS

$$\mathrm{BR}(t \to qZ) < 0.05\%$$ CMS

well above
the SM prediction

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If new physics (NP) at the TeV scale

⇒ the NP flavor structure cannot be anarchic
need some alignment with the SM (or universality)

INTRODUCTION

In many models the SM mixing with the new physics subject to flavor suppression:

- Left-handed fields: $\lambda_L^t : \lambda_L^c : \lambda_L^u \sim 1 : V_{cb} : V_{ub}$
- Right-handed field: $\lambda_R^t : \lambda_R^c : \lambda_R^u \sim 1 : \frac{m_c}{m_t V_{cb}} : \frac{m_u}{m_t V_{ub}}$

can use effective field theory to estimate the flavor violating effects

EFFECTIVE FIELD THEORY

t→cZ:

$$\bar{t}_L\gamma^\mu\sigma_3 c_L(H^\dagger\sigma_3\overset{\leftrightarrow}{D}_\mu H)$$

$$\bar{t}_R\gamma^\mu c_R(H^\dagger\overset{\leftrightarrow}{D}_\mu H)$$

$$\bar{t}_L\gamma^\mu c_L(H^\dagger\overset{\leftrightarrow}{D}_\mu H)$$

$$\Rightarrow \quad \left(g_{tc,L}\bar{t}_L\gamma^\mu c_L + g_{tc,R}\bar{t}_R\gamma^\mu c_R\right) Z_\mu$$

$$g_{tc,L} \sim \frac{g}{2c_W}\frac{v^2}{M_*^2}V_{cb} \qquad g_{tc,R} \sim \frac{g}{2c_W}\frac{v^2}{M_*^2}\frac{m_c}{m_t V_{cb}}$$

(assume that the top mixing is an order one)

M_* - the new-physics scale

EFFECTIVE FIELD THEORY

t→ch:

$$\bar{t}_L \tilde{H} c_R (H^\dagger H) \qquad \bar{c}_L \tilde{H} t_R (H^\dagger H)$$

➡

$$\left(y_{tc,L} \bar{t}_L c_R + y_{tc,R} \bar{t}_R c_L\right) h$$

$$y_{tc,L} \sim \frac{v^2}{M_*^2} \frac{m_c}{v V_{cb}} \qquad y_{tc,R} \sim \frac{v^2}{M_*^2} \frac{m_t}{v} V_{cb}$$

M_* - the new-physics scale

TOP FLAVOR VIOLATION IN COMPOSITE HIGGS MODELS

COMPOSITE HIGGS MODELS

the framework:

- Global SO(5) broken to SO(4), at scale - f.
- Solves the gauge/hierarchy problem.
- The Higgs is a composite and pseudo Nambu-Goldstone boson and can be naturally light.
- Non SM contributions to Zbb are protected by custodial symmetry.

Agashe, Contino, Da-Rold, Pomarol
hep-ph/0605341

COMPOSITE HIGGS MODELS

The framework (continued):

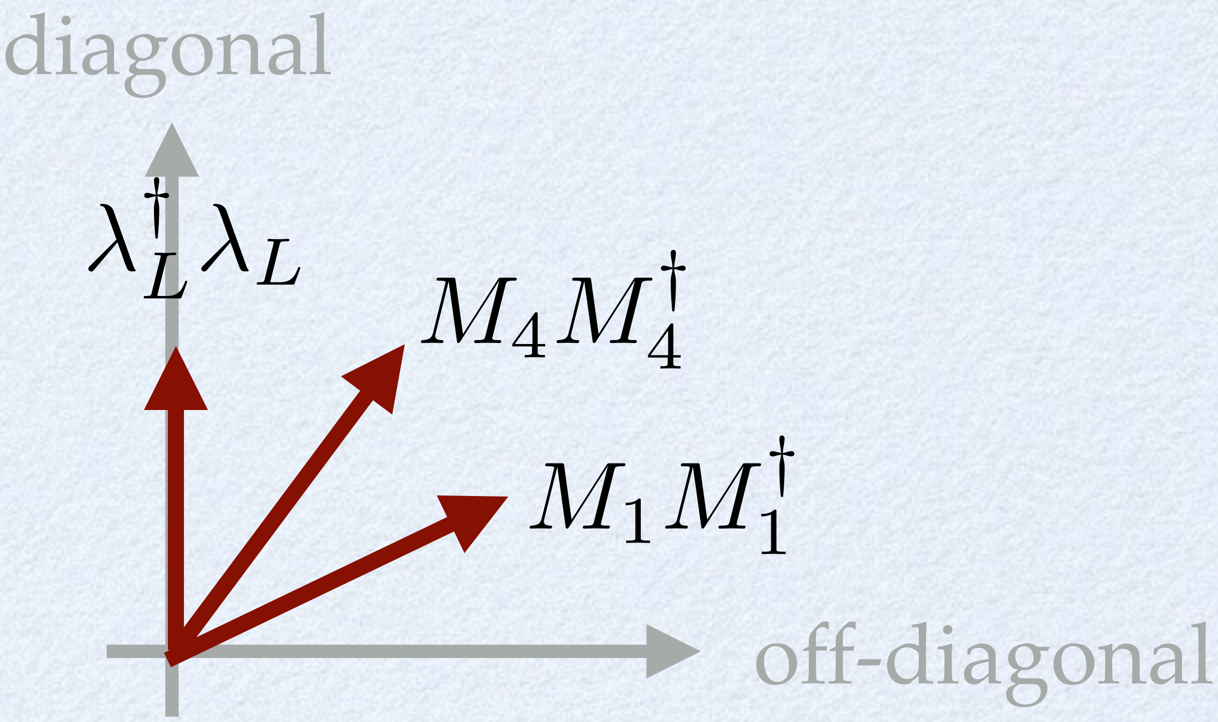
- Two sectors:
  - **Elementary** - massless SM fields
  - **Composite** - additional massive resonances, no flavor structure (anarchic) - characterized by the scale M_*
- Elementary / composite **mixing:**
  - Left: $\lambda_L^t : \lambda_L^c : \lambda_L^u \sim 1 : V_{cb} : V_{ub}$
  - Right: $\lambda_R^t : \lambda_R^c : \lambda_R^u \sim 1 : m_c/m_t V_{cb} : m_u/m_t V_{ub}$
- FCNC are suppressed by the small SM mass and mixing
- Minimizing of the fine-tuning leads to $\lambda_L^t \sim \lambda_R^t$

$$m^i_{\mathrm{SM}} \sim \frac{v}{f} \frac{\lambda_L^i \lambda_R^i}{M_*}$$

THE UP FLAVOR STRUCTURE

The flavor parameters:

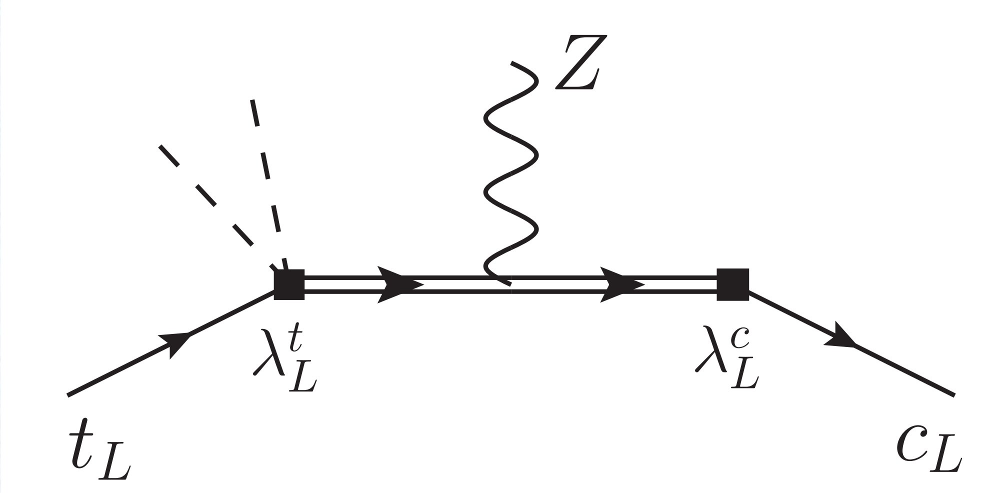
- Vector-like composite mass matrices - M_1, M_4
- Elementary / composite mixing:
  - Left mixing - λ_L
  - Right mixing - λ_R

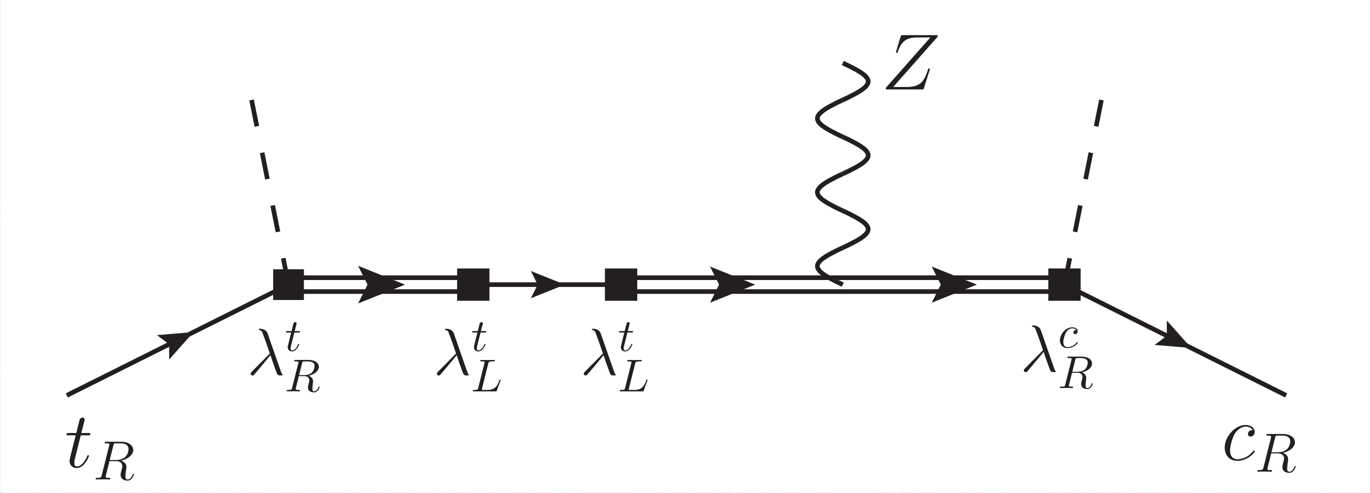


(similar for the right)

Misalignment in the flavor space → Flavor violation

TOP/Z FLAVOR VIOLATION





$$g_{tc,L} \sim \frac{g}{2c_W}\frac{v^2}{2f^2}\frac{\lambda_L^t}{M_*}\frac{\lambda_L^c}{M_*}$$

$$g_{tc,R} \sim \frac{g}{2c_W}\frac{v^2}{f^2}\frac{\lambda_R^t}{M_*}\frac{\lambda_R^c}{M_*}\left(\frac{\lambda_L^t}{M_*}\right)^2$$

$$\mathrm{BR}(t \to cZ) \sim (0.2,\, 0.8) \times 10^{-5}\left(\frac{700\,\mathrm{GeV}}{M_*}\right)^4$$

Right current is larger than the left - can be tested

TOP HIGGS FLAVOR VIOLATION

FROGGATT-NIELSEN

Approximate U(1)'s symmetries

→

Yukawa are suppressed by different powers of the breaking parameters

$$\epsilon_i \simeq \lambda = 0.2$$

Consider two possibilities

- SM + nonrenormalizable terms
- Supersymmetric model + nonrenormalizable terms

FROGGATT-NIELSEN

SM + nonrenormalizable terms:

$$\mathcal{L}_Y = -\lambda^u_{ij} Q_i \bar{U}_j \phi - \frac{\lambda'^u_{ij}}{\Lambda^2} Q_i \bar{U}_j \phi \left(\phi^\dagger \phi\right) + \text{h.c.}$$

$$\Rightarrow \quad Y^u_{ij} = \frac{\sqrt{2} m^u_i}{v} \delta_{ij} + \frac{v^2}{\Lambda^2} (V^u_L \lambda'^u V^{u\dagger}_R)_{ij}$$

$(\phi^\dagger\phi)$ does not carry a FN charge ⇒ λ and λ' have the same parametric structure

$$\epsilon_i \simeq \lambda = 0.2$$

$$Y_{tc} \sim \frac{v^2}{\Lambda^2} \lambda \lesssim 10^{-3} \ll 0.14$$

current bound

FCNC bounds (charm mixing)

$$\frac{v^2}{\Lambda^2} \lesssim 10^{-2}$$

FROGGATT-NIELSEN

Supersymmetric model + nonrenormalizable terms:

$$\mathcal{L}_Y = \lambda^u_{ij} Q_i \bar{U}_j \phi_u + \frac{\lambda'^u_{ij}}{\Lambda^2} Q_i \bar{U}_j \phi_u \left(\phi_u \phi_d\right)$$

⇒ $$(Y^u_h)_{ij} = \frac{c_\alpha}{s_\beta} \frac{m^u_i}{v} \delta_{ij} + \frac{v^2 c_{\alpha+\beta} s_\beta}{2\sqrt{2}\Lambda^2} (V^u_L \lambda'^u V^{u\dagger}_R)_{ij}$$

If $(\phi_u \phi_d)$ carry a FN charge ⇒ λ and λ' have different parametric structure

Use "holomorphic zeros" to align the new sources of flavor violation and avoid FCNC bounds

Leurer, Nir, Seiberg
hep-ph/9310320

FROGGATT-NIELSEN

Supersymmetric model + nonrenormalizable terms:

$$\mathcal{L}_Y = \lambda^u_{ij} Q_i \bar{U}_j \phi_u + \frac{\lambda'^u_{ij}}{\Lambda^2} Q_i \bar{U}_j \phi_u (\phi_u \phi_d)$$

$$\Rightarrow \quad (Y^u_h)_{ij} = \frac{c_\alpha}{s_\beta} \frac{m^u_i}{v} \delta_{ij} + \frac{v^2 c_{\alpha+\beta} s_\beta}{2\sqrt{2}\Lambda^2} (V^u_L \lambda'^u V^{u\dagger}_R)_{ij}$$

Approximate U(1)×U(1) FN symmetry:

$$V^u_L \lambda'^u V^{u\dagger}_R \sim \begin{pmatrix} \lambda^{14} & \boxed{\lambda^{11}} & \lambda^{12} \\ \boxed{\lambda^7} & \lambda^4 & \lambda^5 \\ \lambda^3 & 1 & \lambda^1 \end{pmatrix} \quad \Rightarrow \quad Y_{tc} \sim \frac{v^2}{\Lambda^2} \sim 0.1$$

no problem with charm mixing

SUMMARY

- BR($t \rightarrow cZ$)~10^{-5} with dominant right-handed current is generic in composite Higgs models, even in the presence of custodial protection - can be tested at the next run of the LHC.
- In Froggatt-Nielsen models the bounds from meson mixing push the new physics scale such that the $t \rightarrow ch$ rate is too small to be observed.
- By using further alignment of the new flavor violation sources, as demonstrated in Supersymmetric models, the $t \rightarrow ch$ rates can be much larger and even saturate the current bound.

BACKUP SLIDES

FINE-TUNING

the Higgs potential: $V(h) = \alpha \sin^2 (h/f) + \beta \sin^4 (h/f)$

$$\xi \equiv \sin^2 (\langle h \rangle / f) = -\alpha/2\beta \ll 1$$

typical values: $\beta \sim \frac{N_c}{16\pi^2} \left(\lambda_L^t \lambda_R^t\right)^2 \quad \alpha_{L,R}^t \sim \frac{N_c}{16\pi^2} \left(\lambda_{L,R}^t\right)^2 M_*^2$

the fine-tuning: $\mathrm{FT}^{-1} \sim \frac{-2\beta\,\xi}{\alpha_{L,R}^t} \sim \frac{\min\left[(\lambda_R^t)^2, (\lambda_L^t)^2\right] v^2}{M_*^2 f^2}$

$$\sim \frac{m_t^2}{\max\left[\lambda_{L,R}^t\right]^2} \sim y_t \frac{v^2}{M_* f} \sim \frac{y_t}{g_*} \frac{v^2}{f^2}$$

$\lambda_L^t \sim \lambda_R^t$ minimize the tuning

COMPOSITE TOP/Z FLAVOR VIOLATION

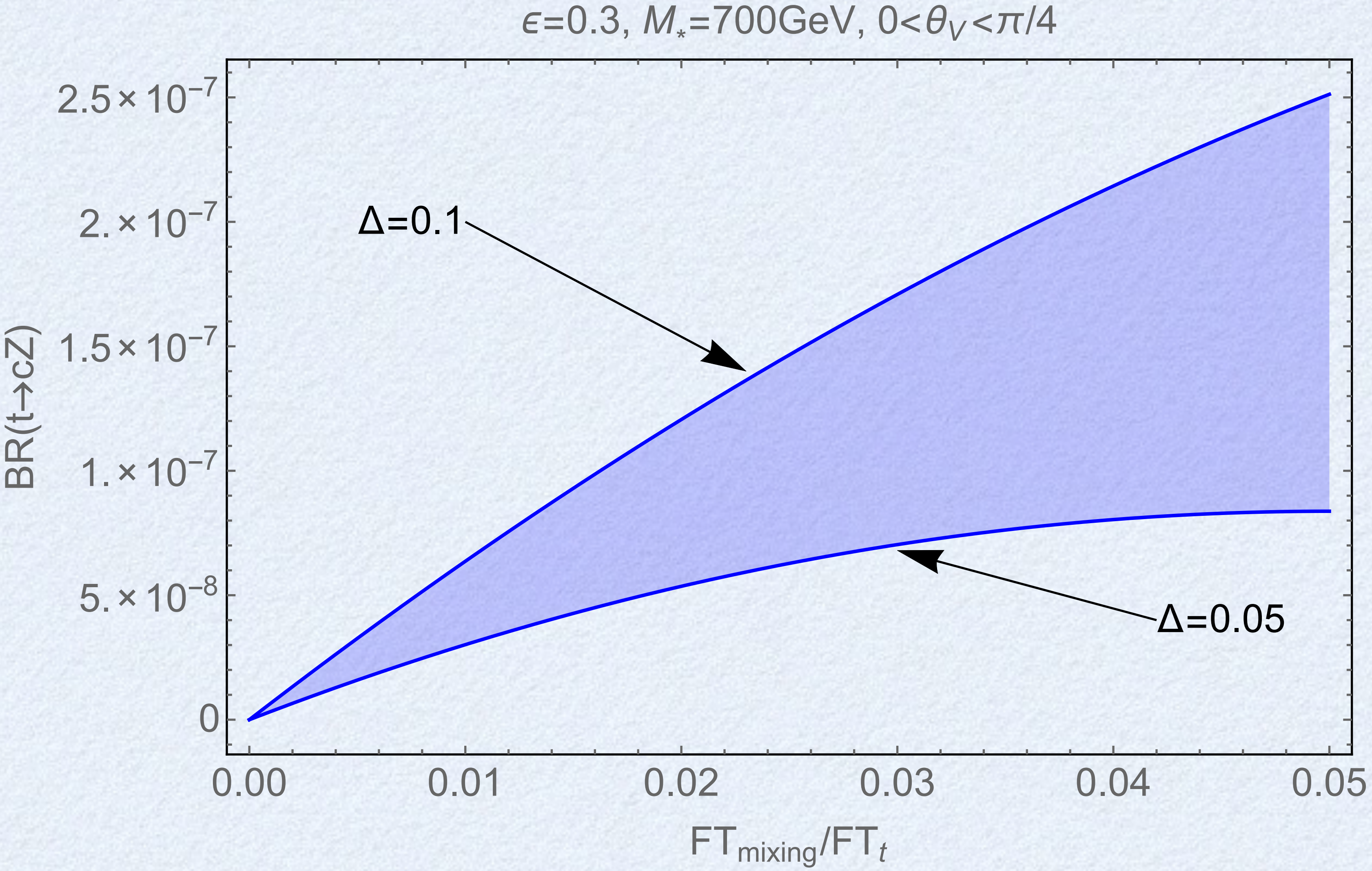
$$\mathcal{L} \supset \bar{u}_L^i \left(m_u^{\rm SM}\right)^{ij} u_R^j + \bar{u}_L^i \left(g_{Z,L}^{\rm SM}\right)^{ij} Z_\mu \gamma^\mu u_L^j + \bar{u}_R^i \left(g_{Z,R}^{\rm SM}\right)^{ij} Z_\mu \gamma^\mu u_R^j$$

$$m_u^{\rm SM} = \frac{\epsilon}{\sqrt{2}} \lambda_L \left[M_4^{-1} - M_1^{-1}\right] \lambda_R \qquad \epsilon \equiv \frac{v}{f}$$

$$g_{Z,L}^{\rm SM} = -\frac{g}{2c_W} \frac{\epsilon^2}{2} \lambda_L \left[\left(M_1^\dagger M_1\right)^{-1} + \left(M_4^\dagger M_4\right)^{-1}\right] \lambda_L^\dagger$$

$$g_{Z,R}^{\rm SM} = -\frac{g}{2c_W} \frac{\epsilon}{\sqrt{2}} \left[m_u^{{\rm SM}\dagger} \lambda_L \left(M_4 M_4^\dagger M_4\right)^{-1} \lambda_R + h.c.\right]$$

FINE-TUNING VS. FLAVOR VIOLATION



PARAMETER COUNTING

2 generation limit no CPV:

- $M_1, M_4, \lambda_L, \lambda_R$->$0$: $SO(2)^6$= $SO(2)_Q \times SO(2)_U \times SO(2)_{Q4,L} \times SO(2)_{Q4,R} \times SO(2)_{U1,L} \times SO(2)_{U1,R}$
- 6 real 2×2 matrices ($M_1, M_4, \lambda_{L1}, \lambda_{L4}, \lambda_{R1}, \lambda_{R4}$)
- $\lambda_{L1}= \lambda_{L4}$, $\lambda_{R1} = \lambda_{R4}$ respect SO(5) - finite potential. Flavor does commute with the global SO(5).
- single elementary (composite) mixing for λ_L, λ_R and 1 and 4 have same eigenvalues : 24-6 = 18 parameters.
- $SO(2)^6$ allows to remove 6 unphysical parameters.
- 12 parameters: 8 eigenvalues ($M_1, M_4, \lambda_L, \lambda_R$)+ 4 mixing angles (misalignment between the matrices)..