The Potential of Minimal Flavour Violation

Rodrigo Alonso

Introduction
Minimal Flavour Violation
The Dynamics Behind MFV

The Potential
Bifundamental Approach
Construction of the Potential
Minimum of the Potential
Fundamental Approach
The Potential

Conclusions

The Potential of Minimal Flavour Violation

Rodrigo Alonso

Departamento de Física Teórica
Universidad Autónoma de Madrid
& IFT-CSIC

based on the work with
Belén Gavela, Luca Merlo
& Stefano Rigolin
arXiv:1103.2915 [hep-ph]

Rencontres de Moriond, 2011

Outline

1. Introduction
   - Minimal Flavour Violation
   - The Dynamics Behind MFV
2. The Potential
   - Bifundamental Approach
     - Construction of the Potential
     - Minimum of the Potential
   - Fundamental Approach
     - The Potential
3. Conclusions

Minimal Flavour Violation (MFV)

MFV is a symmetry approach to the flavour problem

- The MFV hypothesis: *The Yukawa couplings are the only sources of flavour violation in and* ***beyond*** *the Standard Model*[1].
- Generations are distinguished by masses and mixing angles; in the limit of zero masses the SM presents an extended symmetry group:

$$G_f = SU(3)_{Q_L} \times SU(3)_{D_R} \times SU(3)_{U_R} \times \cdots$$

$$D_R = (d_R, s_R, b_R)^T \quad D_R \sim (1, 3, 1 \cdots)$$

This is the symmetry of the high scale theory. At this scale the Yukawa couplings are also invariant:

$$\overline{Q}_L Y_D D_R H \qquad\qquad Y_D \sim (3, \bar{3}, 1)$$

At low energies Y_D adquires a v.e.v. and breaks the flavour symmetry. Y_U & Y_D are the *only* directions of flavour breaking.

Such an hypothesis is strongly supported by current data

[1] G. D'Ambrosio, G. Giudice, G. Isidori, and A. Strumia, Nucl. Phys. B645 (2002)

Introduction
Minimal Flavour Violation
The Dynamics Behind MFV
The Potential
Bifundamental Approach
Construction of the Potential
Minimum of the Potential
Fundamental Approach
The Potential
Conclusions

The Dynamics Behind MFV

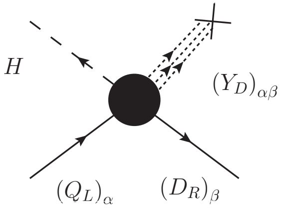
In this scheme Y_U & Y_D have a *dynamical origin*. At some regime the Yukawa Interaction involves extra fields increasing the dimension of the 'Yukawa Operator':

- **Dimension Group Representation**
- Dimension 5 $\leftrightarrow$ Bifundamental Fields

$$\overline{Q}_L \frac{\Sigma_u}{\Lambda} D_R H \qquad \Sigma_d \sim (3, \bar{3}, 1)$$

- Dimension 6 $\leftrightarrow$ Fundamental Fields

$$\overline{Q}_L \frac{\chi_d^L \chi_d^{R\dagger}}{\Lambda^2} D_R H \qquad \begin{array}{l} \chi_d^L \sim (3,1,1) \\ \chi_d^R \sim (1,3,1) \end{array}$$



- Dimension 7 ; Georgi & Chivukula's originals idea: a fermion condensate[1]

The next question is how these fields adquire a v.e.v.
Through a **Scalar Potential** ...

[1] Phys. Lett. B188 (1987) 99.

Construction of the Potential

Dimension 5 Yukawa Operator

The potential will also respect the flavour symmetry, so it will be built with the G_f invariants:

$$Tr\left(\Sigma_u\Sigma_u^\dagger\right)\,, \quad \det\left(\Sigma_u\right)\,, \quad Tr\left(\Sigma_u\Sigma_u^\dagger\Sigma_d\Sigma_d^\dagger\right)\,,$$
$$Tr\left(\Sigma_d\Sigma_d^\dagger\right)\,, \quad \det\left(\Sigma_d\right)\,, \quad \cdots$$

These invariants can be expressed in terms of masses and mixing angles (2 generations):

$$\langle\Sigma_u\rangle = \Lambda\cdot V^\dagger Diag\{y_{u_i}\}\,, \qquad \langle\Sigma_d\rangle = \Lambda\cdot Diag\{y_{d_i}\}\;;$$
$$Tr\left(\left\langle\Sigma_u\Sigma_u^\dagger\Sigma_d\Sigma_d^\dagger\right\rangle\right) = \frac{1}{2}\Lambda^4\left[\left(y_c^2-y_u^2\right)\left(y_s^2-y_d^2\right)\cos 2\theta_c + \cdots\right]$$

The most general Potential is:

$$V = \sum_{i=u,d}\left(-\mu_i^2 Tr\left(\Sigma_i\Sigma_i^\dagger\right) - \tilde{\mu}_i^2\det\left(\Sigma_i\right)\right) +$$
$$\sum_{i,j=u,d}\left(\lambda_{ij}Tr\left(\Sigma_i\Sigma_i^\dagger\right)Tr\left(\Sigma_j\Sigma_j^\dagger\right) + \tilde{\lambda}_{ij}\det\left(\Sigma_i\right)\det\left(\Sigma_j\right) + \cdots\right)\cdots$$

Minimum of the Potential

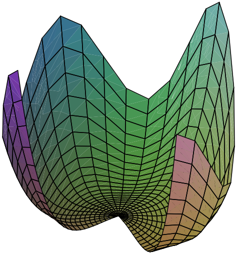
Dimension 5 Yukawa Operator

The minimum of the Potential is given by:

$$\frac{\partial V}{\partial y_i} = 0 \qquad \frac{\partial V}{\partial \theta_i} = 0$$

Take the angle for example:

$$\frac{\partial V}{\partial \theta_c} \propto \left(y_c^2 - y_u^2\right)\left(y_s^2 - y_d^2\right)\sin 2\theta_c = 0$$



Can the actual masses and mixings fit naturally in the minimum of the Potential?

The answer is worse than NO .

- Not only we have to input the hierarchy of masses in the potential parameters, wich was to expect but $\cdots$
- To accommodate the mixing we must introduce wild fine tunnings of $O(10^{-10})$ and nonrenormalizable terms of dimension 8

Fundamental Fields

Dimension 6 Yukawa Operator

Let's first have a carefull look at the Yukawa structure:

$$Y_D = \frac{\langle \chi_d^L \chi_d^{R\,\dagger} \rangle}{\Lambda^2} \qquad Y_U = \frac{\langle \chi_u^L \chi_u^{R\,\dagger} \rangle}{\Lambda^2}$$

The Yukawas are composed of two 'vectors'. Such a structure has only one eigenvalue, one mass . This fact becomes evident when rotating the v.e.v.s of the fields to the form:

$$V_L^\dagger Y_D V_{D_R} = \frac{\left|\chi_d^L\right| \left|\chi_d^R\right|}{\Lambda^2} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix},$$

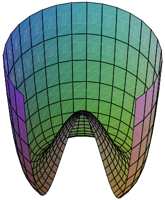
$$V_L^\dagger Y_U V_{U_R} = \frac{\left|\chi_u^L\right| \left|\chi_u^R\right|}{\Lambda^2} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$

This means a hierarchy among the masses and an angle only by construction! .

Minimum of the Potential

Dimension 6 Yukawa Operator

The invariants are:



$$\chi_u^{L\dagger}\chi_u^L\,,\qquad \chi_u^{R\dagger}\chi_u^R\,,\qquad \chi_d^{L\dagger}\chi_d^L\,,$$
$$\chi_d^{R\dagger}\chi_d^R\,,\qquad \chi_u^{L\dagger}\chi_d^L = \left|\chi_u^L\right|\left|\chi_d^L\right|\cos\theta_c\,.$$

We can fit the angle and the masses in the Potential; as an example:

$$V' = \lambda_u\left(\chi_u^{L\dagger}\chi_u^L - \frac{\mu_u^2}{2\lambda_u}\right)^2 + \lambda_d\left(\chi_d^{L\dagger}\chi_d^L - \frac{\mu_d^2}{2\lambda_d}\right)^2$$
$$+\lambda_{ud}\left(\chi_u^{L\dagger}\chi_d^L - \frac{\mu_{ud}^2}{2\lambda_{ud}}\right)^2 + \cdots$$

Whose minimum sets (2 generations):

$$y_c^2 = \frac{\mu_u^2}{2\lambda_u\Lambda^2}\qquad y_s^2 = \frac{\mu_d^2}{2\lambda_d\Lambda^2}\qquad \cos\theta = \frac{\mu_{ud}^2\sqrt{\lambda_u\lambda_d}}{\mu_u\mu_d\lambda_{ud}}$$

Introduction
Minimal Flavour Violation
The Dynamics Behind MFV
The Potential
Bifundamental Approach
Construction of the Potential
Minimum of the Potential
Fundamental Approach
The Potential
Conclusions

Conclusions

- The Potential of MFV requires further assumptions about the underlying dynamics.
- The outcome is radically varying with the assumptions.
- A first approximation to masses and mixings fits naturally in a symmetry breaking mechanism of the flavour group

Thank you for your attention

Conclusions

- The Potential of MFV requires further assumptions about the underlying dynamics.
- The outcome is radically varying with the assumptions.
- A first approximation to masses and mixings fits naturally in a symmetry breaking mechanism of the flavour group

Thank you for your attention