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On Higgs-Dependent Yukawas

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Abstract: Motivated by the Higgs-dependent Yukawa constants idea in the D-brane inspired standard models, the quark mass hierarchy through appropriate Higgs-dependent canstants are generated and their consistencies are examined.

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In the last few years there has been growing interest in the intersecting D-brane models [1, 2]. These models aims to systematically classify all possible configurations [3, 4], and seeking an acceptable effective low energy theory which reproduces the success of the Standard Model (SM) [5, 6, 7, 8]. However, the problem of mass hierarchy remains one of the most open question in gauge theories of fundamental interactions. In the present paper, we address the problem in the context of type IIA superstring using intersecting $D6$-branes, where fermions as well as Higgs fields appear at the intersections and are located at different positions in the internal space being a six-dimensional factorizable torus [9, 10]. The number of fermion generations is related to the multiplicity of the corresponding intersecting number.

Based on the simplest and most economical D-brane configuration which can incorporate the SM gauge symmetry [8, 11], we examine the quark Yukawa sector with the presence of two Higgs doublets and discuss the family hierarchy through consistent Yukawa components. In effective low energy theories modeled from intersecting D-branes configurations, the Yukawa superpotential terms are subject to additional restrictions from abelian symmetries and anomaly cancelation conditions. In a minimal spectrum, it is shown that several Yukawa couplings are absent in the perturbative superpotential. Thus the mass of all quarks can be obtained only when additional Higgs doublets are considered leading to smaller, comparable or even larger entries in the mass matrices, depending of course on the magnitude of the various Higgs vevs. Moreover, in a realistic

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D-brane SM analogue one could envisage to interpret the quark mass spectrum through the Higgs dependent couplings effects. This is a generic characteristic with rather exciting and unprecedented implications on the low energy phenomenology of these constructions.

Here we focus on a vacuum configuration involving four stacks of D6-branes: a stack of three (color stack a), a stack of two (weak stack b), and two single branes c and d. The hypercharge embedding is $Y = Q_a/6 - Q_c/2 - Q_d/2$. Our basic assumption is that in the minimal D-brane models the resulting fermions Yukawa couplings are sensitive to the Higgs fields content,

$$\mathbf{Y}^f = \mathbf{Y}^f \left(H, H^{'}, .. \right), \tag{1}$$

where H, $H^{'}$, .. represent the various Higgs fields in the configuration giving rise to a spectrum satisfying all anomaly cancellation conditions, and some other conditions coming from tadpole cancellation [12]. Here we restrict ourself to quark sector This consists of the three SM quark generations and the needed Higgs doublets. Let $q_{i_1} : (1, -1, 0, 0)$ and $Q_{i_2} : 2\,(1, 1, 0, 0)$ be the three quark doublets, $u : 3\,(-1, 0, 1, 0)$ $d : 3\,(-1, 0, -1, 0)$ the right handed partners and the two Higgses $H_u : (0, -1, -1, 0)$ and $H_d : (0, 1, 1, 0)$ required in orientIfold realizations. The indices i_1, i_2 introduced take one, two values respectively to serve for quark famliy assignment,

$$(i_1, i_2) = \begin{array}{l} (1, (2, 3)) \mapsto q_1, Q_2, Q_3, \\ (2, (1, 3)) \mapsto q_2, Q_1, Q_3, \\ (3, (2, 1)) \mapsto q_3, Q_2, Q_1. \end{array} \tag{2}$$

According to their charges (q_a, q_b, q_c, q_d), a number of useful Yukawa couplings is missing at the perturbative level. Indeed, depending on the particular assignment of the quark generation (2), three possible coupling matrix textures arise with the up down complementary generation relation

$$Y^u_{i_2 j} + Y^d_{i_1 j} = \mathbf{Y}_{ij}. \tag{3}$$

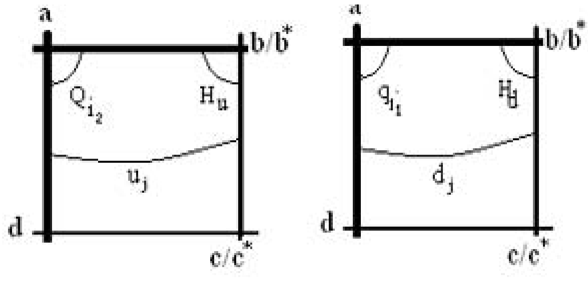

Fig. 1 The allowed Yukawa mass terms for both up and down quarks

The most obvious possibility of deriving the requested couplings is to extend the Higgs sector by introducing new multiplets $H^{'}$ with suitable charges $H^{'}_u : (0, 1, -1, 0)$ and $H^{'}_d : (0, -1, 1, 0)$ emerging in the intersection of the two convenient branes,

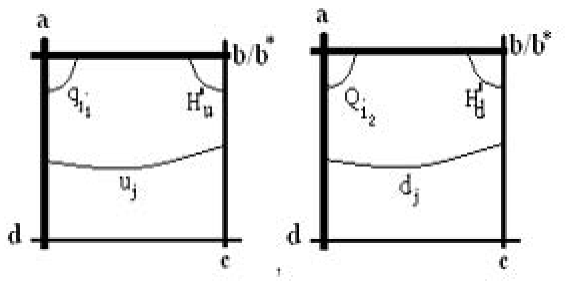

Fig. 2 The generated Yukawa mass terms for both up and down quarks.

Taking into account the additional Higgses, the resulting Yukawa couplings can be expanded into two terms as,

$$\mathbf{Y}_{ij}\left(H, H^{'}\right) = \sum_{i_1,i_2} g_{ij}\left(\frac{\langle H'\rangle}{\langle H\rangle}\right)^{n_i}, \tag{4}$$

where the appropriate powers, assumed family dependent, n_i explain the hierarchical pattern of quark masses. The g_{ij}'s are dimensionless coupling constants, which we assume to be of the same order. So the new terms fill the missing couplings in the up and down matrices such as,

$$\begin{aligned} \mathbf{Y}^u_{ij}\left(H, H^{'}\right) &= g_{i_1 j}\left(\frac{\langle H'_u\rangle}{\langle H_u\rangle}\right)^{n^u_{i_1}} + g_{i_2 j}\left(\frac{\langle H'_u\rangle}{\langle H_u\rangle}\right)^{n^u_{i_2}}, \\ \mathbf{Y}^d_{ij}\left(H, H^{'}\right) &= g_{i_1 j}\left(\frac{\langle H'_d\rangle}{\langle H_d\rangle}\right)^{n^d_{i_1}} + g_{i_2 j}\left(\frac{\langle H'_d\rangle}{\langle H_d\rangle}\right)^{n^d_{i_2}}. \end{aligned} \tag{5}$$

When the Higgs fields develop vacuum expectation values, the quarks attain hierarchical masses through the family dependent powers of the Higgs vevs ratios. According to (2) three different coupling matrix textures are possible, of course, not all of them can be compatible with the known data and due to the complementary texture zero structure of the up and down quark coupling matrices (3), the consitent textures seem those where the up and down quark Yukawa matrices are aligned in the way that both of them manifest the same hierarchical structure. In addition, since generated in the same intersection of the barne stacks, the two doublet quark flavors Q_{i_2} reveal a neighbouring hierarchy an therefore could correspond to the two fisrt light generations while the remaining quark doublet q_{i_1} will refer to the heavy third one. So we end up with the following assignment as well as the resulting order of the various vevs,

$$\mathbf{Y}^u = \begin{pmatrix} g_{11} & g_{12} & g_{13} \\ g_{21} & g_{22} & g_{23} \\ g_{31} \langle H_u' \rangle / \langle H_u \rangle & g_{32} \langle H_u' \rangle / \langle H_u \rangle & g_{33} \langle H_u' \rangle / \langle H_u \rangle \end{pmatrix}, \tag{6}$$

$$\mathbf{Y}^d = \begin{pmatrix} g_{11} \langle H_d' \rangle / \langle H_d \rangle & g_{12} \langle H_d' \rangle / \langle H_d \rangle & g_{13} \langle H_d' \rangle / \langle H_d \rangle \\ g_{21} \langle H_d' \rangle / \langle H_d \rangle & g_{22} \langle H_d' \rangle / \langle H_d \rangle & g_{23} \langle H_d' \rangle / \langle H_d \rangle \\ g_{31} & g_{32} & g_{33} \end{pmatrix}. \tag{7}$$

In the first set, small couplings occupy the two first matrix lines of both up and down quarks, while larger entries are in the remaining ones. This leads to,

$$\left\langle H_u^{'} \right\rangle \ \rangle \ \langle H_u \rangle \, , \ \left\langle H_d^{'} \right\rangle \ \langle \ \langle H_d \rangle \, , \tag{8}$$

for the Higgs vevs and to,

$$n_{i_1}^u \ = 1, \ \ n_{i_2}^u = 0, \ \ n_{i_1}^d = 0, \ \ n_{i_2}^d = 1, \tag{9}$$

values for the corresponding hierarchical powers. As can be noted, even if this texture seems the be the consistent one containing the correct family assignment and quark mass hierarchy, the distinction among the different texture relys on the magnitude of the new entries. This will be dictated when the order of magnitude of the Higgs vevs ratios will be specified and thus considerable adjustment of the parameters is needed to derive the observed quark data.

The fermion masses is a wide class of effective low energy models emerging from intersecting D-brane configurations. In these constructions the Yukawa superpotential terms are subject to additional restrictions from abelian symmetries and anomaly cancelation conditions. In this work we have shown that in a minimal spectrum, several Yukawa couplings are absent in the perturbative superpotential and by consequence the mass of all quarks generations are obtained only when additional Higgs doublets are considered leading to smaller, comparable or even larger entries in the mass matrices, depending of course on the magnitude of the various Higgs vevs. Hence, in a realistic D-brane SM analogue one could envisage to interpret the quark mass spectrum through the Higgs dependent couplings effects.

This is a generic characteristic with rather exciting and unprecedented implications on the low energy phenomenology of these constructions, even if other alternative remain possible [13, 14, 15, 16], attributing the observed family hierarchy to the different magnitude perturbative Higgs dependant couplings.

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