EXACT STANDARD MODEL STRUCTURES FROM INTERSECTING BRANES

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I discuss two types of non-supersymmetric string model constructions that give at low energy exactly the Standard model (SM) with no additional matter/and or gauge group factors. The construction is based on D6 branes intersecting at angles in a compactification of type IIA theory on a decomposable orientifolded $T^6$ torus. The first type is based on five and six stack SM-like constructions at the string scale while, the other construction is based on a four stack GUT left-right symmetric structure centered around the Pati-Salam $SU(4)_C \times SU(2)_L \times SU(2)_R$ gauge group. All classes of models exhibit important phenomenological properties including a stable proton and sizes of neutrino masses in consistency with neutrino oscillation experiments. The models are non-SUSY, but amazingly, they allow the existence of supersymmetric particles!

1. Introduction

One of most difficult tasks that string theory has to phase today is the construction of non-SUSY vacua with exactly the observable SM gauge group and interactions at low energies of order $M_Z$. The latter had become possible only recently, as vacua with exactly the SM at low energy have been constructed either from D6 branes intersecting over $^1^2$ an orientifolded $T^6$ torus $^3^4^5^6^7$ or from intersecting D5 branes on an orientifold of $T^2 \times T^4 / Z_N$ $^8^9$. For constructions of SUSY vacua $^b$ see $^10$. In this talk, we will focused on the four stack GUT constructions of $^4$ as well the the five and six stack SM constructions of $^6^7$.

$^a$In the absence of a dynamical mechanism that can select a particular string vacuum.

$^b$In the context of intersecting branes.
2. Five Stack SM’s

The models start with five stacks of D6 branes making a \( U(3) \times U(2) \times U(1)_c \times U(1)_d \times U(1)_e \) group structure at the string scale. The models are constructed as a deformation of the four stack models of around the QCD intersection numbers \( I_{ab} = 2, I_{ac} = 3 \). The SM spectrum is localized in the intersections as in table (1). The solution to the RR tadpole cancellation conditions

\[
\sum_a N_a n_a^1 n_a^2 n_a^3 = 16, \\
\sum_a N_a m_a^1 m_a^2 n_a^3 = 0, \\
\sum_a N_a m_a^1 n_a^2 m_a^3 = 0, \\
\sum_a N_a n_a^1 m_a^2 m_a^3 = 0.
\] (1)

that guarantee the absence of non-abelian gauge anomalies is given in table 1.a. The choice of tadpole solutions of table 1.a satisfy all tadpole equations in (1) but the first, the latter giving

\[
\frac{9n_a^2}{\beta^1} + 2\frac{n_a^1}{\beta^2} + \frac{n_a^2}{\beta^1} + \frac{n_a^2}{\beta^1} + N_D \frac{2}{\beta^1 \beta^2} = 16.
\] (2)

*Effectively an \( SU(3) \times SU(2) \times U(1)_a \times U(1)_b \times U(1)_c \times U(1)_d \times U(1)_e \), as each \( U(N_i) \) will give rise to an \( SU(N_i) \) charged under the associated \( U(1) \) gauge group factor that appears in the decomposition \( SU(N_a) \times U(1)_a \).
The mixed anomalies of the $U(1)$’s with the non-abelian gauge groups are cancelled through a generalized Green-Schwarz mechanism \(^3\) that makes massive the $U(1)$’s coupled to the RR fields $B^i_2$, $i = 1, 2, 3$.

\[
B_2^1 \wedge \left( \frac{-2\hat{e} \beta^1}{\beta^2} \right) F^b, \quad B_2^3 \wedge \left( \frac{e \beta^2}{\beta^3} \right) (9 F^a + 2 F^d + F^c),
\]

\[
B_2^3 \wedge \left( \frac{3\hat{e} n^2_a F^a + n^1_b F^b + n^1_c F^c - \hat{e} n^2_d F^d - \hat{e} n^2_e F^e}{2\beta^3} \right). \quad (3)
\]

In an orthogonal basis, the rest of the $U(1)$’s, are the SM hypercharge

\[
(3n^2_a + 3n^2_d + 3n^2_e) \neq 0, \quad Q^l = n^1_c (Q_a - 3Q_d - 3Q_e) - \frac{3\hat{e} \beta^2 (n^2_a + n^2_d + n^2_e)}{2\beta^3} Q_c. \quad (4)
\]

only when (4) satisfies the condition,

\[
n^1_c = \frac{\hat{e} \beta^2}{2\beta^3} (n^2_a + n^2_d + n^2_e), \quad (5)
\]

as well the

\[
U(1)^{(5)} = \left( -\frac{3}{29} + \frac{3}{28} \right) F^a - \frac{1}{29} F^d + \frac{1}{28} F^e. \quad (6)
\]

The latter $U(1)$ may be broken by demanding that the open string sector $ac$ respects $N = 1$ SUSY, giving us a constraint on the tadpole parameter $n^2_e = 0$ as well allowing the presence of $uR$. Also the presence of (6) gives the constraint $n^2_e = (-28/9)n^2_a$. In a similar way we can treat the construction of higher order deformation, with only SM at low energy of order $M_Z$, involving the six-stack \(^7\) structure of table (2) as well the Pati-Salam GUTS \(^4\) of table (3).

| $N_i$ | $(n^i_1, m^i_1)$ | $(n^i_2, m^i_2)$ | $(n^i_1, m^i_2)$ |
|-------|-----------------|-----------------|-----------------|
| $N_a = 3$ | $(1/\beta, 0)$ | $(n^a_2, e\beta^1)$ | $(3, \epsilon/2)$ |
| $N_b = 2$ | $(n^a_2, -\epsilon\beta^1)$ | $(1/\beta, 0)$ | $(\epsilon/2, 1)$ |
| $N_c = 1$ | $(n^a_1, e\beta^1)$ | $(1/\beta, 0)$ | $(0, 1)$ |
| $N_d = 1$ | $(1/\beta, 0)$ | $(n^a_2, 2e\beta^2)$ | $(1, -\epsilon/2)$ |
| $N_e = 1$ | $(1/\beta, 0)$ | $(n^a_2, e\beta^2)$ | $(1, -\epsilon/2)$ |

Table 1.a. Tadpole solutions of D6-branes wrapping numbers. The solutions depend on five integer parameters, $n^2_a, n^2_d, n^2_e, n^1_b, n^1_c$, the NS-background $\beta^i$ and the phase parameters $\epsilon = \pm 1, \bar{\epsilon} = \pm 1$.

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Table 2. Low energy fermionic spectrum of the six stack string scale $SU(2)_C \otimes SU(2)_L \otimes U(1)_a \otimes U(1)_b \otimes U(1)_c \otimes U(1)_d \otimes U(1)_e \otimes U(1)_f$, type I D6-brane model together with its $U(1)$ charges. Note that at low energies only the SM gauge group $SU(3) \otimes SU(2)_L \otimes U(1)_Y$ survives.

| Matter Fields | Intersection | $Q_a$ | $Q_b$ | $Q_c$ | $Q_d$ | $Q_e$ | $Q_f$ | $Y$ |
|--------------|--------------|-------|-------|-------|-------|-------|-------|-----|
| $QL$         | (3, 2)       | 1     | -1    | 0     | 0     | 0     | 0     | 1/6 |
| $Q_L$        | 2(3, 2)      | 1     | 1     | 0     | 0     | 0     | 0     | 1/6 |
| $U_R$        | 3(3, 1)      | -1    | 0     | 1     | 0     | 0     | 0     | -2/3|
| $D_R$        | 3(3, 1)      | -1    | 0     | -1    | 0     | 0     | 0     | 1/3 |
| $L^1$        | (1, 2)       | 0     | -1    | 0     | 1     | 0     | 0     | -1/2|
| $L^2$        | (1, 2)       | 0     | -1    | 0     | 0     | 0     | 0     | -1/2|
| $L^3$        | (1, 2)       | 0     | -1    | 0     | 0     | 0     | 0     | -1/2|
| $N^1_R$      | (1, 1)       | 0     | 0     | 1     | -1    | 0     | 0     | 0   |
| $E^1_R$      | (1, 1)       | 0     | 0     | -1    | -1    | 0     | 0     | 1   |
| $N^2_R$      | (1, 1)       | 0     | 0     | 1     | -1    | 0     | 0     | 0   |
| $E^2_R$      | (1, 1)       | 0     | 0     | -1    | 0     | 0     | 0     | 1   |
| $N^3_R$      | (1, 1)       | 0     | 0     | 1     | 0     | -1    | 0     | 0   |
| $E^3_R$      | (1, 1)       | 0     | 0     | -1    | 0     | 0     | -1    | 1   |

Table 3. Fermionic spectrum of the $SU(4)_C \times SU(2)_L \times SU(2)_R$, PS-A class of models together with $U(1)$ charges.

| Fields      | Intersection | $SU(4)_C \times SU(2)_L \times SU(2)_R$ | $Q_a$ | $Q_b$ | $Q_c$ | $Q_d$ |
|-------------|--------------|----------------------------------------|-------|-------|-------|-------|
| $F_L$       | $I_{abc} = 3$| $3 \times (4, 2, 1)$                    | 1     | 1     | 0     | 0     |
| $F_R$       | $I_{ac} = -3$| $3 \times (4, 1, 2)$                    | -1    | 0     | 1     | 0     |
| $X_L$       | $I_{bd} = -12$| $12 \times (1, 2, 1)$                   | 0     | -1    | 0     | 1     |
| $X_R$       | $I_{cd} = -12$| $12 \times (1, 1, 2)$                   | 0     | 0     | -1    | -1    |
| $\omega_L$ | $I_{aa}^*$   | $12 \beta^2 \tilde{c} \times (6, 1, 1)$| $2\tilde{c}$| 0 | 0 | 0 |
| $\omega_R$ | $I_{aa}^*$   | $6 \beta^2 \tilde{c} \times (10, 1, 1)$| $-2\tilde{c}$| 0 | 0 | 0 |
| $s_L$       | $I_{aa}^*$   | $24 \beta^2 \tilde{c} \times (1, 1, 1)$| 0     | 0     | 0     | $-2\tilde{c}$|

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