On the Phenomenology of Four Dimensional Gepner Models

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String Phenomenology and Dynamical Vacuum Selection

Motivation

- Search for “realistic” vacua which can be obtained from String Theory
- Huge number of candidates
- Not all of them have a nice phenomenology in 4 dimensions
- Essentially two steps to take:

  1. Start from a string/M-theory in D = 10/11, compactify it to 4 dimensions imposing consistency conditions (tadpole cancellation, no anomalies) and immediate phenomenological constraints (e.g. 3 generations, no chiral exotics)

  2. Further study of the phenomenological properties of the model (masses of the particles, neutrino masses etc.)

First Step (Compactification)

- Various compactification methods (Calabi-Yau, orientifolds, orbifolds, fluxes, their combinations)

- An effective way to search for realistic string vacua uses four-dimensional extended superconformal theories

- Properties of internal SCFT are reflected in properties of D = 4 space time,

  e.g. (N = 2 SCFT corresponds to N = 1 space time SUSY, N = 4 SCFT corresponds to N = 2 space time SUSY) T. Banks, L. Dixon 88; T. Banks, L. Dixon, D. Friedan, E. Martinec 88

- Further intensive studies in this direction

N = 2 SCFT

$$
\begin{aligned}
T(z)T(w) &= \frac{c/2}{(z-w)^4} + \frac{2\,T(w)}{(z-w)^2} + \frac{\partial_w T(w)}{z-w} + \cdots \ , \\
T(z)G^{\pm}(w) &= \frac{3/2}{(z-w)^2}\,G^{\pm}(w) + \frac{\partial_w G^{\pm}(w)}{z-w} + \cdots \ , \\
T(z)J(w) &= \frac{J(w)}{(z-w)^2} + \frac{\partial_w J(w)}{z-w} + \cdots \ , \\
G^{+}(z)G^{-}(w) &= \frac{2\,c/3}{(z-w)^3} + \frac{2J(w)}{(z-w)^2} + \frac{2T(w) + \partial_w J(w)}{z-w} + \cdots \ , \\
J(z)G^{\pm}(w) &= \pm\frac{G^{\pm}(w)}{z-w} + \cdots \ , \\
J(z)J(w) &= \frac{c/3}{(z-w)^2} + \cdots \ .
\end{aligned}
$$

N = 1 space time SUSY

$$Q_\alpha = \oint dz e^{-\frac{\phi}{2}} S_\alpha \Sigma, \quad Q_{\dot\alpha} = \oint dz e^{-\frac{\phi}{2}} C_{\dot\alpha} \overline{\Sigma},$$

- Where Σ is a chiral primary with the charge 3/2, Φ is the ghost and S is the fermionic emission operator
- And vice versa, having chiral primaries of N = 2 SCFT with charge ±3/2 one can construct space time supercharges.
- Analogous consideration applies also for N= 2 space time SUSY

Gepner Models

- Correspond to N = 1 SUSY in 4 dimensions (closed string compactification, related to mirror symmetry)

- Corresponding internal SCFT is a tensor product of several minimal models with central charges

$$c_i = \frac{3P_i}{P_i + 2}$$

- Total central charge

$$c = \sum_i c_i = 9$$

- Primary fields Φ(l,m,s) have conformal weight

$$h = \frac{l(l+2)}{4(P+2)} - \frac{m \pm 1^2}{4(P+2)} + \frac{s^2}{8}$$

- And U(1) charge

$$Q = \frac{m \pm 1}{P+2} \pm \frac{s}{2}$$

Construction of Four Dimensional Models

- Contrsuct the characters in (l,m,s) sector

$$\chi^l_{ms} = Tr_{\mathcal{H}^l_{ms}}(e^{2\pi i z J_0} e^{2\pi\tau(L_0 - \frac{c}{24})})$$

- Combine with SO(2) characters V_2, S_2, O_2 and C_2
- Construct Klein bottle, Moebius strip and annulus amplitudes

$$\tilde{K} \sim \frac{1}{2}\sum_i \Gamma_i^2 \chi_i(il), \quad \tilde{A} \sim \sum_i B_i^2 \chi_i(il)\chi_i(it), \quad \tilde{M} \sim \frac{1}{2}\sum_{i,a} 2^{\frac{D}{2}+1}\tilde{M}_i\chi_i(il + \frac{1}{2})$$

- Require tadpole cancellation
- This gives around 1900 realisations of the Standard Model (P. Anastasopoulos, T. Dijkstra, E. Kiritsis, B. Schellekens, 06)

- Do any of these models have phenomenologically attractive features?

Spectra of the four dimensional models (general features)

- There are fields from the Standard Model and fields from the hidden sector
- Standard model spectrum appears from the set of branes (a, b, c, d branes)
- a branes correspond to the strong U(3) group, b branes to the weak group U(2) or Sp(2), c branes are necessary to generate hypercharges and there is an extra brane d.
- Therefore, we have (pseudo)anomolous gauge symmetries $U(1)_3$, $U(1)_w$, $U(1)_c$ and $U(1)_d$.
- There are also hidden sector branes which are necessary to cancel tadpoles

General Features of Models under Consideration

- The weak group does not have a U(1) factor
- The gauge group in the hidden sector is either is SU(2) or O(2). The SU(2) group is phenomenologically more attractive since the gaugino condensate might happen to break SUSY in the visible sector
- Net chirality in the hidden sector is zero
- All mixed anomalies of the strong group with $U(1)_3$, $U(1)_c$ and $U(1)_d$ is zero

$$K_{IJ} = Tr[Q_J(T^aT^a)_I],$$

$$K_{IJ} = \begin{pmatrix} 0 & 0 & 0 \\ \frac{9}{2} & \frac{1}{2} & 1 \\ -\frac{9}{2} & -\frac{9}{2} & -3 \\ 0 & 0 & 0 \end{pmatrix}$$

Masses of all quarks should be generated via the Higgs mechanism

Further Properties of the Spectrum

- Universal right neutrino changed under $U(1)_c$ and $U(1)_d$
- Missing right neutrinos are obtained from the hidden sector brane being complete singlets under the Standard Model group
- Not all quarks get masses via renormalisable trilinear terms in the superpotential
- However, they can obtain masses via higher order quartic terms in the superpotential
- Possibility of vacuum expectation values for scalar superpartners of right neutrinos

Further Properties

- A neutrino mass matrix is generated in the usual way
- Not all eigenvalues are different from zero in this setup
- A possible way to generate non-zero values is via vacuum expectation values of scalars from the hidden sector or via d brane instantons.
- The μ-term is allowed by the symmetries at hand so gauginos and neutralinos are massive
- The baryon number is an exact symmetry which correponds to $U(1)_3$ while the lepton number violating terms are allowed in principle.

Conclusions

- Gepner models give interesting four dimensional physics which has nice phenomenological features
- They give minimal supersymmetric Standard Model spectra and some extra fields in the hidden sector
- More detailed study of neutrino masses is needed
- Gaugino condensation