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Nuclear Physics B 713 (2005) 83–135

NUCLEAR PHYSICS B

The statistics of supersymmetric D-brane models

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Received 17 December 2004; accepted 10 February 2005

Available online 8 March 2005

Abstract

We investigate the statistics of the phenomenologically important D-brane sector of string compactifications. In particular for the class of intersecting D-brane models, we generalise methods known from number theory to determine the asymptotic statistical distribution of solutions to the tadpole cancellation conditions. Our approach allows us to compute the statistical distribution of gauge theoretic observables like the rank of the gauge group, the number of chiral generations or the probability of an $SU(N)$ gauge factor. Concretely, we study the statistics of intersecting branes on T^2 and $T^4/\mathbb{Z}_2$ and $T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$ orientifolds. Intriguingly, we find a statistical correlation between the rank of the gauge group and the number of chiral generations. Finally, we combine the statistics of the gauge theory sector with the statistics of the flux sector and study how distributions of gauge theoretic quantities are affected.

PACS: 11.25.Mj

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0550-3213/$ – see front matter
doi:10.1016/j.nuclphysb.2005.02.005

1. Introduction

For many years, string theorists have studied various kinds of string compactifications with the main motivation to find a model one day which resembles the Standard Model of particle physics, which we know is a good effective description of nature around the weak scale. Of course, it is very compelling that string theory in some sense predicts (or at least contains) gravity and at the same time also gauge theory, but it turned out to be a very difficult problem to be more precise about the predictions for the gauge theory sector at low energies. There were simply too many possible candidates which at best resembled the Standard Model in certain aspects but not in its full glory. However, one could also say that if we had constructed the Standard Model already in a few attempts, we could have simply been very lucky or more probably would have just found one of a vast number of stringy realisations of the Standard Model.

Recall that in the eighties the weakly coupled heterotic string was thought to be the best candidate to deliver a realistic model. Various (supersymmetric) constructions, like orbifolds, bosonic lattices, free fermion constructions, Calabi–Yau manifolds in toric varieties, Landau–Ginzburg and Gepner models etc. were studied and partly classified in a large number of publications. Even today it is not clear whether there exist finitely or infinitely many heterotic string backgrounds.

With the advent of D-branes in the mid nineties, new classes of phenomenologically attractive string compactifications were found where the gauge theory is realised by the open strings ending on D-branes. Different constructions were proposed like orientifolds with branes on singularities or intersecting D-branes. It was also realised that the string scale does not necessarily have to be close to the Planck scale, as in D-brane constructions low string scale models can exist and would lead to a completely new phenomenology in the TeV range [1]. In this case, supersymmetry would no longer be necessary for solving the gauge hierarchy problem.

In addition, with the extension of the relevant dimensions to eleven and even twelve, new geometric compactifications were possible like M-theory on G_2 manifolds or F-theory on Calabi–Yau fourfolds. Since among these different classes of string models various S and T dualities operate, not all constructions were considered to be independent, but rather provide descriptions in different regimes of the M-theory moduli space. It was clear by then that there exist very many string vacua, but nevertheless people hoped that maybe one could find a realistic model out of these, say, 10^{10} vacua.[1]

Moreover, with the study of flux compactifications [3–7] some additional progress was made: First, flux compactifications allowed to solve some of the problems the former purely geometric models notoriously had. In particular, certain fluxes induce an effective potential that still possesses supersymmetric minima, which allows to freeze (some of) the moduli generically appearing in string theory. Second, it was also possible to break supersymmetry in a controlled way by turning on additional internal flux components. Finally, by taking also some non-perturbative effects into account, for the first time strong evidence was given that non-supersymmetric meta-stable de Sitter vacua do exist in string

[1] Numbers of this order appeared for instance in the classification of CY fourfolds [2].