JHEP HYPER VERSION

RECEIVED: *July 1, 1999*, ACCEPTED: *July 7, 1999*

Non-supersymmetric large N gauge theories from type 0 brane configurations

Adi Armoni and Barak Kol

School of Physics and Astronomy,
Beverly and Raymond Sackler Faculty of Exact sciences,
Tel Aviv University, Ramat Aviv, 69978, Israel
Email: armoni@post.tau.ac.il, barak@beauty.tau.ac.il

ABSTRACT: We use dyonic brane configurations of type 0 string theory to study large N non-supersymmetric $4d$ gauge theories. The brane configurations define theories similar to the supersymmetric ones which arise in type II. We find the non-SUSY analogues of $\mathcal{N}=2$ and $\mathcal{N}=1$. In particular we suggest new non-SUSY CFT's and a brane realization of a non-SUSY Seiberg duality.

KEYWORDS: Brane Dynamics in Gauge Theories, Conformal Field Models in String Theory, D-branes.

JHEP07(1999)011

Contents

1. Introduction

In recent years we learned that D-branes can be used as a tool to study supersymmetric gauge theories [1] (for a recent review and references see [2]). Using brane configurations of type IIA/B string theory the Seiberg-Witten curves of $\mathcal{N} = 2$ [3] were given a geometrical realization [4], the running of the coupling was related to the bending of the *NS* branes [4], and $\mathcal{N} = 1$ Seiberg duality [5] was realized by the exchange of the *NS* supports [6, 7].

Though much understanding was gained for supersymmetric theories, branes configurations failed to teach us about non-supersymmetric gauge theories, since non-SUSY brane configurations are usually not stable.

An important direction in the study of non-SUSY gauge theories is the use of branes in the context of type 0 string theory [8]. Type 0 string theory is defined on the world sheet exactly like type II, except that a non-chiral GSO projection is performed. The resulting sectors of the theory are the $(NS-, NS-), (NS+, NS+)$ and a doubled set of R-R fields. The low-energy fields of the theory are therefore a tachyon, the bosonic (NS, NS) fields of type II and two-copies of R-R fields. Accordingly two types of D-branes exists. We will refer to the two kinds as 'electric' and 'magnetic', and to a pair of electric and magnetic as 'dyonic'. The 'dyonic' combination of branes was called also 'untwisted' by [9], as it belongs to the untwisted sector in their description of type 0 as an orbifold of M-theory.

Klebanov and Tseytlin argued that in the background of D-branes, the R-R flux will cure the tachyon instability and that the gauge theory on the branes is perfectly ok. Using the electric D3 branes they constructed an SU(N) gauge theory with six adjoint scalars [8] and studied its behavior in an AdS/CFT inspired way [10]. For recent related works see [11, 12].

Another interesting construction uses a stack of N coincident dyonic D3 branes [11]. In this case each dyonic brane can be thought of as a pair made of an electric and a magnetic brane. The strings that connect the electric-electric and the magnetic-magnetic branes yields a $\mathrm{SU}^e(N) \times \mathrm{SU}^m(N)$ gauge theory with 6 magnetic adjoint scalars and 6 electric adjoint scalars. In addition the strings that connect electric-magnetic branes give rise to additional 4 bifundamental Weyl fermions in the $(N, \bar{N})$ and another 4 bifundamental Weyl fermions in the $(\bar{N}, N)$ [13]. The model has similarities to the orbifold models of Kachru and Silverstein [14]. Although it cannot be obtained by a string orbifold of type IIB, it can be viewed as a field theory "orbifold" truncation (in the sense of ref. [15]) of $\mathcal{N} = 4\,\mathrm{U}(2N)$. Super Yang-Mills [16]. An interesting remark is that although the theory is non-SUSY it admits a moduli space of vacua [17, 18].

The gravity solution of this configuration is an $AdS_5 \times S^5$ space with constant dilaton and zero tachyon. Therefore Klebanov and Tseytlin interpreted this theory as a non-SUSY CFT [11]. The fact that the stringy solution of type 0 dyonic D3 branes is the same as that of type II is not surprising. When we consider dyonic branes in type 0 (i.e., identifying electric and magnetic branes), a solution with zero tachyon and the same massless bosonic fields as in type II would exist. The only additional conditions are large N and small enough 't Hooft coupling [11]. The reason for the similarity is that in these cases, the S-matrix of sphere amplitudes for fields common to type 0 and type II coincide [8]. Therefore the low-energy effective action of type 0 is almost the same. The differences are the existence of two R-R fields and the presence of the tachyon which is coupled to other fields with even powers. As a result, we find a solution of the equations of motion in which the tachyon is zero and the two kinds of R-R fields are identified. This is exactly the type II solution. An important remark is the necessity of large N. Higher order contributions to the tree level action (string loops) may contribute terms which do not have even powers of tachyon, hence the zero tachyon solution cease to exist. However, these contributions are suppressed in the large N limit. Another remark is that the R-R flux is expected to shift the tachyon mass to positive values only when the 't Hooft coupling is small enough. Therefore only in this limit, the solution with zero tachyon is expected to be stable.

From the field theory point of view, the class of theories that we consider here fall into the class of "orbifold field theories". It was shown in ref. [15], and later generalized to the case of product groups in [19], that certain truncation of supersymmetric field theories would yield a non-supersymmetric gauge theory with exactly the same large N Green functions (in the untwisted sector). As we will show, the type 0 truncation corresponds to such an orbifold projection.

An important feature of these theories is that they exist only for small enough values of the 't Hooft coupling ([11] find $\lambda < 100$ for the "$\mathcal{N} = 4$" theories). The orbifold non-SUSY theories inherit only a subset of the operators. In particular the operator $\mathrm{tr}\, F_1^2 - \mathrm{tr}\, F_2^2$ does not exist in the SUSY theory. This operator couples to the tachyon in the bulk. As long as λ is small enough, the two point function of this operator is non-tachyonic. However, for large values of λ the dimension of the operator becomes complex and the non-SUSY theory is not well defined. In the parent SUSY theory there is no such operator and therefore it is well defined for all values of λ.[1]

In this paper, we would like to generalize the D3 solution to the more complicated cases when we include *NS* branes. Since the above reasoning should hold in this case also, we expect that the non-supersymmetric theory which lives on the analogous brane configuration would share many of the properties of supersymmetric one. In particular, in the large N limit, these theories would have the same perturbative Green functions and hence the same perturbative beta function. An important remark is that the validity of this approach is subjected to the assumption of non-perturbative equivalence of the non-SUSY untwisted sector and the parent. The simplest example is the $\mathcal{N} = 2$ brane configuration of type II. Here we also expect to have exactly flat dyonic directions and a mass spectrum in the dyonic sector which is Bose-Fermi degenerate, though non-SUSY. For the special case of $N_\mathrm{f} = 2N_\mathrm{c}$ we will have a large N non-SUSY CFT. Another class of large N non-SUSY CFT's can be constructed from the type 0 analogue of the brane-boxes configurations [20, 21]. The type 0 analogue of the $\mathcal{N} = 1$ configuration yields a non-supersymmetric version of Seiberg duality. In particular, the type 0 theories are expected to maintain the phase structure in the $N_\mathrm{f}/N_\mathrm{c}$ axis. These theories are a special case of the theories considered in the past by Schmaltz who showed that the large N "orbifold field theories" of $\mathcal{N} = 1$ admits duality [19]. It is interesting that in the present case the duality can be understood also via branes.

Some open questions are raised by this discussion. We discuss large N non-SUSY field theories which have the same dynamics as supersymmetric ones. In particular these theories have the same number of bosons and fermions. One wonders if there is any symmetry (not SUSY) which is responsible for that. In the supersymmetric parent the particle spectrum is divided to BPS and non-BPS. We expect the distinction to carry over to the non-SUSY theory, such that the masses of the "BPS" particles is given by a BPS-like formula. Is there an intrinsic way to distinguish the two kinds?

The organization of the paper is as follows: in section 2 we describe the type 0 string theories and their relation to the II string theories. In section 3 we explain the orbifold truncation of field theory and its relation to type 0 theories. Section 4 is devoted to the study of the non-SUSY analogues of $\mathcal{N} = 2$. In section 5 we consider the non-SUSY version of Seiberg duality. We describe finite non-SUSY models using brane boxes in section 6. Section 7 is devoted to conclusions.

[1]We thank O. Aharony, A. Rajaraman and A. Tseytlin for clarifying this point.

2. Type 0 string theory

Type II A/B string theories have non-supersymmetric analogues called type 0 A/B. The type 0 theories are constructed via a non-chiral GSO projection which keeps the following bosonic sectors

$$\begin{aligned}
&\text{type 0A} : (NS-, NS-) \oplus (NS+, NS+) \oplus (R+, R-) \oplus (R-, R+) \\
&\text{type 0B} : (NS-, NS-) \oplus (NS+, NS+) \oplus (R+, R+) \oplus (R-, R-)
\end{aligned}$$

The tree level type 0B action from the $(NS+, NS+)$ sector is exactly the same as the type IIB action [8]

$$S = -2 \int d^D x \sqrt{G} e^{-2\Phi} \left(R + 4(\partial_n \Phi)^2 - \frac{1}{12} H^2_{mnk} \right) , \tag{2.1}$$

where H_{mnk} is the field strength of the anti-symmetric two-form B_{mn}. The action of the tachyon which comes from the $(NS-, NS-)$ sector is

$$S = \int d^D x \sqrt{G} e^{-2\Phi} \left(\frac{1}{2} G^{mn} \partial_m T \partial_n T + \frac{1}{2} m^2 T^2 \right) , \tag{2.2}$$

where $m^2 = (2 - D)/4\alpha'$ is the mass of the tachyon. The leading R-R terms in the action are

$$S = \int d^D x \sqrt{G} h_{(n+1)}(T) |F_{n+1}|^2 , \tag{2.3}$$

where F_{n+1} is the field strength of the *dyonic* R-R fields and $h_{(n+1)}(T)$ describes the coupling of the tachyon to the R-R fields. Note that although the functions $h_{(n+1)}(T)$ are not known, symmetry arguments for the coupling to the 'electric' and 'magnetic' forms require that these functions should be even in the dyonic case.

It is therefore clear that a solution in a dyonic background with $T = 0$ is the same as the solution of the bosonic fields of type II supergravity. While this statement is trivial in the tree level, it is certainly wrong for $g_s > 0$ [11], since torus amplitudes generate odd tachyon contributions to the action. Therefore similarities between supersymmetric type II gauge theories and non-supersymmetric type 0 theories are expected to occur in the large N limit, like the D3 type 0 case [11], the orbifold models of Kachru and Silverstein [14] and the non-supersymmetric version of Seiberg $\mathcal{N} = 1$ duality which was considered by Schmaltz [19].

Note also that in order to have a stable $T = 0$ solution, we must shift the tachyon mass. Since the function $h(T)$ contains a T^2 part, for large enough R-R flux the tachyon mass-squared becomes positive. In the background of a Dp brane, this condition translates into a requirement of small 't Hooft coupling.

JHEP07(1999)011

3. "Type 0" projected field theories

Given a brane configuration in type II string theory, one can construct a new non-supersymmetric field theory by considering the same brane configuration in type 0 with dyonic branes replacing the type II D-branes. This procedure can be given an intrinsic definition in field theory, which we shall discuss now. The new field theory will be constructed by a certain (orbifold) projection of a SUSY field theory. All amplitudes with untwisted external legs of the non-SUSY theory will be identical, in the large N limit, to amplitudes of the parent theory.

For "$\mathcal{N}=4$" (the type 0 version of $\mathcal{N}=4$) this was shown by [16] who put the type 0 projection in a form suitable for the more general methods of [14, 23, 15]. One starts with a $\mathrm{U}(2N_{\mathrm{c}})\mathcal{N}=4$ theory and performs a $\mathbf{Z}_2$ projection, keeping only the invariant fields. The $\mathbf{Z}_2$ is embedded into the $\mathbf{Z}_4$ center of the SO(6) R-symmetry and its generator acts on the gauge group as $\gamma=\left[\begin{smallmatrix}1 & 0\\ 0 & -1\end{smallmatrix}\right]$, where the entries are $N_{\mathrm{c}}\times N_{\mathrm{c}}$ blocks. The resulting spectrum is made of bosons in the adjoint of $\mathrm{SU}^e(N_{\mathrm{c}})\times\mathrm{SU}^m(N_{\mathrm{c}})$ and fermions in the bifundamental. The projection will preserve all amplitudes in the large N limit, since if satisfies the condition that the matrix γ be traceless.

The generalization to theories with less SUSY and with the addition of flavor was discussed by [19]. As SUSY QCD-like theories include matter with indices in a $\mathrm{SU}(2N_{\mathrm{f}})_L\times\mathrm{SU}(2N_{\mathrm{f}})_R$ global symmetry, they are not explicitly included in the previous discussion that assumes matter in the adjoint. One needs to embed the $\mathbf{Z}_2$ into the flavor group as well. The flavor indices are divided into electric and magnetic in the same manner as the color indices. All fields in QCD-like theories carry two indices which are either color-color or color-flavor. The projected matter content turns out to be made, again, of bosons when both indices are of the same kind (say electric-electric), and fermions for magnetic-electric, where now each index can be either color or flavor. In [19] it was checked and proven that the large N amplitudes are preserved. An important remark is that the non-SUSY theory contains operators, such as $\mathrm{tr}\,F_1^2-\mathrm{tr}\,F_2^2$, which do not exist in the parent theory. These operators may become tachyonic (their anomalous dimension may become complex) and therefore the non-SUSY theory will be sick.

4. The "$\mathcal{N}=2$" brane configuration

Consider the type 0 analogue of an $\mathcal{N}=2$ theory with gauge group $\mathrm{SU}(N_{\mathrm{c}})$ and N_{f} matter hypermultiplets. We refer to it as a "$\mathcal{N}=2$" theory. To determine the matter content one can either use the "type 0" projection of a $\mathrm{SU}(2N_{\mathrm{c}})$ theory with $2N_{\mathrm{f}}$ hypers, or read it off the appropriate brane configuration, as we shall. In type II, the relevant brane configuration is a stack of N_{c} "color" D4 branes extending between two $NS\,5$ supports, and N_{f} semi-infinite "flavor" D4's ending on the supports. Strings

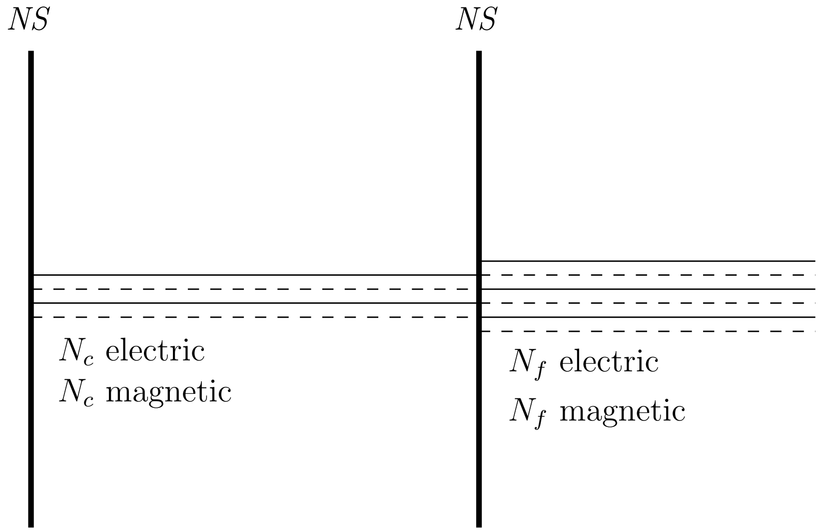

Figure 1: The "$\mathcal{N} = 2$ "type 0 brane configuration. Each dyonic brane can be viewed as a pair of electric and magnetic branes.

stretched between the color branes give the vectors in the adjoint, while the strings between the color and flavor branes give hypers in the fundamental. In passing to type 0, we replace both color and flavor D4's by dyonic D4's — a mix of an equal number of electric and magnetic branes.

One can now read the matter content after recalling that electric-electric (EE) or magnetic-magnetic (MM) strings are bosons, while electric-magnetic (EM) strings are fermions. The matter content is summarized in table 1 below.

	$\mathrm{SU}^e(N_\mathrm{c})\times$	$\mathrm{SU}^m(N_\mathrm{c})\times$	$\mathrm{SU}^e(N_\mathrm{f})\times$	$\mathrm{SU}^m(N_\mathrm{f})$
vector	adj.	1	1	1
vector	1	adj.	1	1
2 scalars	adj.	1	1	1
2 scalars	1	adj.	1	1
2 fermions	$\square$	$\overline{\square}$	1	1
2 fermions	$\overline{\square}$	$\square$	1	1
complex scalar	$\square$	1	$\overline{\square}$	1
complex scalar	$\overline{\square}$	1	$\square$	1
complex scalar	1	$\square$	1	$\overline{\square}$
complex scalar	1	$\overline{\square}$	1	$\square$
Weyl fermion	$\square$	1	1	$\overline{\square}$
Weyl fermion	$\overline{\square}$	1	1	$\square$
Weyl fermion	1	$\square$	$\overline{\square}$	1
Weyl fermion	1	$\overline{\square}$	$\square$	1

Table 1: The matter content of the "$\mathcal{N} = 2$" theory.

It is immediately seen that the "$\mathcal{N}=2$" theory has the same 1-loop beta function as its parent $\mathcal{N}=2$ theory

$$\beta = 2N_{\rm c} - N_{\rm f}\,. \tag{4.1}$$

In comparison with the original $\mathcal{N}=2$ theory we have the same number of fields in the fundamental, while we traded the gauginos in the adjoint with fermions in the bifundamental (and its complex conjugate). But these two representations have the same group theoretic factor $N_{\rm c} = T(\text{adj}) = 2N_{\rm c}T(\text{fund}), T(R)\delta^{ab} = \text{tr}_R[T^aT^b]$. However, other group theoretical factors of the two representations do differ, and so will higher loop computations (for finite $N_{\rm c}$).

One can hope for simplifications in the large $N_{\rm c}$ limit. In addition to keeping the 't Hooft coupling $\lambda = g^2_{\rm YM}N_{\rm c}$, fixed, we fix the flavor ratio $\nu_{\rm f} = N_{\rm f}/N_{\rm c}$ and the scale of mass of the W's (we are assuming that the large $N_{\rm c}$ theory has a moduli space).

For "$\mathcal{N}=4$" theories is was proven [16, 23, 24, 15] that in the large N limit, it has the same untwisted amplitudes as the parent $\mathcal{N}=4$ — one views both U$(N_{\rm c})$ "$\mathcal{N}=4$" and U$(N_{\rm c}),\mathcal{N}=4$ as projections of U$(2N_{\rm c})$, $\mathcal{N}=4$, and hence correlation functions of fields which are shared by both theories (namely, untwisted bosons in the adjoint) must be the same. As discussed in the previous section, we find that this is the case for the "$\mathcal{N}=2$" theories as well. Supporting evidence comes from the gravitational background of the type 0 brane configuration — as the type 0 background is identical to the one in type II, and given the field theory — gravity correspondence [10], one expects the theories to have the same amplitudes. This implies some exact results for these non-SUSY large $N_{\rm c}$ theories: the $N_{\rm f} = 2N_{\rm c}$ theory would be exactly conformal. For any $\nu_{\rm f}$ the theories would have exact dyonic flat directions, leading to an (infinite dimensional) moduli space. For "$\mathcal{N}=4$" a moduli space is expected to exist as a consequence of the no force between dyonic 3 branes in type 0 [8, 18]. And finally, the mass of dyonic "BPS" particles would be expected to be free of corrections. In particular, the masses of the W's are expected to be the same as of the supersymmetric theory, since the relevant Green functions are the same.

5. "$\mathcal{N}=1$" and Seiberg duality

Let us consider now the type 0 analogue of $\mathcal{N}=1$ SQCD. The supersymmetric (electric) theory consists of a SU$(N_{\rm c})$ vector multiplet and two chiral SU$(N_{\rm f})$ multiplets. The brane realization of the theory is similar to the $\mathcal{N}=2$ configuration and it is obtained by rotating one of the $NS\,5$ branes such that half of the supersymmetries are broken. Passing to the type 0 theory, the matter content is summarized in the following table:

	$\mathrm{SU}^e(N_\mathrm{c})$	$\times\mathrm{SU}^m(N_\mathrm{c})$	$\times\mathrm{SU}^e(N_\mathrm{f})$	$\times\mathrm{SU}^m(N_\mathrm{f})$	$\times\mathrm{SU}^e(N_\mathrm{f})$	$\times\mathrm{SU}^m(N_\mathrm{f})$
vector	adj.	1	1	1	1	1
vector	1	adj.	1	1	1	1
fermion	$\square$	$\overline{\square}$	1	1	1	1
fermion	$\overline{\square}$	$\square$	1	1	1	1
scalar	$\square$	1	$\overline{\square}$	1	1	1
scalar	$\overline{\square}$	1	1	1	$\square$	1
scalar	1	$\square$	1	$\overline{\square}$	1	1
scalar	1	$\overline{\square}$	1	1	1	$\square$
fermion	$\square$	1	1	$\overline{\square}$	1	1
fermion	$\overline{\square}$	1	1	1	1	$\square$
fermion	1	$\square$	$\overline{\square}$	1	1	1
fermion	1	$\overline{\square}$	1	1	$\square$	1

Table 2: The content of the electric "$\mathcal{N} = 1$" theory.

One may consider also a magnetic theory which is based on $\mathrm{SU}(N_\mathrm{f} - N_\mathrm{c})$ gauge group, N_f flavors and elementary Meson field. The type 0 analogue of this theory is

	$\mathrm{SU}^e(\tilde{N}_\mathrm{c})$	$\times\mathrm{SU}^m(\tilde{N}_\mathrm{c})$	$\times\mathrm{SU}^e(N_\mathrm{f})$	$\times\mathrm{SU}^m(N_\mathrm{f})$	$\times\mathrm{SU}^e(N_\mathrm{f})$	$\times\mathrm{SU}^m(N_\mathrm{f})$
vector	adj.	1	1	1	1	1
vector	1	adj.	1	1	1	1
fermion	$\square$	$\overline{\square}$	1	1	1	1
fermion	$\overline{\square}$	$\square$	1	1	1	1
scalar	$\overline{\square}$	1	$\square$	1	1	1
scalar	$\square$	1	1	1	$\overline{\square}$	1
scalar	1	$\overline{\square}$	1	$\square$	1	1
scalar	1	$\square$	1	1	1	$\overline{\square}$
fermion	$\overline{\square}$	1	1	$\square$	1	1
fermion	$\square$	1	1	1	1	$\overline{\square}$
fermion	1	$\overline{\square}$	$\square$	1	1	1
fermion	1	$\square$	1	1	$\overline{\square}$	1
scalar	1	1	$\overline{\square}$	1	$\square$	1
scalar	1	1	1	$\overline{\square}$	1	$\square$
fermion	1	1	$\overline{\square}$	1	1	$\square$
fermion	1	1	1	$\overline{\square}$	$\square$	1

Table 3: The content of the magnetic "$\mathcal{N} = 1$" theory. $\tilde{N}_\mathrm{c} = N_\mathrm{f} - N_\mathrm{c}$.

Seiberg showed that the electric and the magnetic theories describes the same IR physics. The duality was realized geometrically via an exchange of the *NS* branes [6, 7]. We claim that the large N (keeping $\nu_\mathrm{f} = N_\mathrm{f}/N_\mathrm{c}$ fixed) type 0 electric and magnetic theories are also dual. The field theory reasonings, for a wider class of theories, was given in [19].

The branes gives a simple evidence that $\mathcal{N}=1$ duality holds. One may simply repeat the same steps of [6]. The dyonic branes dynamics of type 0 is identical to that of type II and therefore starting with the electric theory one would end with the magnetic theory.

The field theory arguments in favor of the duality are based on [19]. Since the Green functions of the untwisted sector, in the large N, are identical, it follows that the type 0 field theory has the same phase structure and dynamics as the type II field theory and therefore duality between the supersymmetric theories implies duality between the non-SUSY ones.

In particular it is easy to check that the one loop beta function of the electric theory type 0 theory is

$$\beta = 3N_{\mathrm{c}} - N_{\mathrm{f}}\,, \tag{5.1}$$

exactly as of the $\mathcal{N}=1$ theory. Moreover, the field theory analysis of [15, 19] suggests that a conformal window exists for $(3/2)N_{\mathrm{c}} < N_{\mathrm{f}} < 3N_{\mathrm{c}}$. Another simple check is the anomaly. Both the type 0 electric theory and magnetic theory have the same global anomalies. The reason is [19] that the anomalies are calculated by planar diagrams which are the same in the non-SUSY theory and its parent. For instance,

$$\mathrm{SU}^3(N_{\mathrm{f}}) \sim N_{\mathrm{c}}\,, \qquad \mathrm{SU}^2(N_{\mathrm{f}})\,\mathrm{U}_B(1) \sim N_{\mathrm{c}}\,. \tag{5.2}$$

Thus, though the theory is not supersymmetric we have a good understanding of the IR physics and the phase structure.

6. Brane boxes and CFT's

Brane boxes suggest a nice realization of finite four-dimensional supersymmetric gauge theories via type IIB string theory [20, 21]. Let us review, briefly, the construction of these configurations. The reader is referred to [21] for a comprehensive discussion. Consider a set of N D5 branes along 012346 directions, a set of parallel *NS* branes along 012345 directions and additional set of parallel *NS*$'$ branes along 012367 directions. The models that we consider here are on a torus in the 46 directions. The resulting theory is, generically, $\mathcal{N}=1$ gauge theory in four dimensions. The theories are described in figure 2.

Let us denote the number of horizontal boxes by k and the number of vertical boxes by k'. Each box describes an $\mathrm{SU}(N)$ gauge group which interacts with the other boxes via open strings. The allowed directions of strings (which are drawn as arrows) are north, south, east, west and two of the diagonals: northwest and southeast. Note that the northeast and the southwest diagonal arrows are not allowed [20]. Each

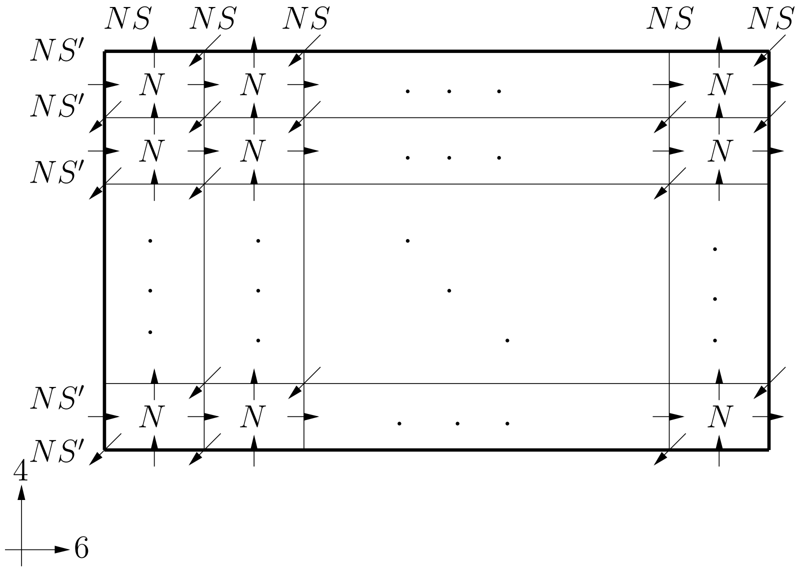

Figure 2: Finite brane-boxes theories. There are $k \times k'$ boxes. The drawn 46 plane is a torus.

triangle of arrows form a contribution to the superpotential W. The sign of the contribution to the superpotential is dictated by the handedness of the triangle. Thus a generic finite model is an $\mathrm{SU}(N) \times \cdots \times \mathrm{SU}(N)$ (kk' times) gauge theory with bifundamental matter. In addition there might be additional matter due to the intersection of the *NS*-*NS′* branes. This issue was addressed lately in the framework of 'diamonds' models [22], where it was pointed out that the intersection singularity should be blown up as give rise to a more involved diamond interactions. However, in the specific case that we present here, namely a zero size diamond, we will adopt the conservative view that the field content should be the same as of [21]. The *NS* / *NS′* branes do not bend since there are the same number of D-branes in each side of them. In addition there is a superpotential. The form of the superpotential together with the fact that the *NS* / *NS′* branes do not bend guarantee that these models are indeed finite.

The case of $k = k' = 1$ is special. In this case the supersymmetry is enhanced to $\mathcal{N} = 4$. When $k = 1,\ k' > 1$ the supersymmetry is enhanced to $\mathcal{N} = 2$. The generic case $k, k' > 1$ corresponds to $\mathcal{N} = 1$ supersymmetry.

These models can be constructed in type 0 also. In the large N we will have non-supersymmetric CFT's which are analogues to the above $\mathcal{N} = 4$, $\mathcal{N} = 2$ and $\mathcal{N} = 1$ models. The rule of constructing the type 0 gauge theory is described in section 3. Put N electric and N magnetic D-branes in each box. Accordingly the gauge group will be $\mathrm{SU}^e(N) \times \mathrm{SU}^m(N) \times \cdots \times \mathrm{SU}^e(N) \times \mathrm{SU}^m(N)$ (kk' electric and kk' magnetic groups). Strings that connect electric-electric or magnetic-magnetic branes are bosons whereas strings that connect electric-magnetic branes are fermions.

Let us consider the special example of $k = k' = 2$. The supersymmetric model consist of a gauge group $\mathrm{SU}(N) \times \mathrm{SU}(N) \times \mathrm{SU}(N) \times \mathrm{SU}(N)$ with vector like matter in the bifundamental of each of the two groups.

The analogous type 0 theory contains eight gauge groups. The vectors ("gluons") are in the adjoints of the gauge groups, the "gauginos" are in the bifundamental of $\mathrm{SU}^e(N) \times \mathrm{SU}^m(N)$ pairs which originate from a same gauge group, i.e., eight Weyl fermions. The matter consist of six complex scalars ("squarks") in $\mathrm{SU}^e(N) \times \mathrm{SU}^e(N)$ and six complex scalars in $\mathrm{SU}^m(N) \times \mathrm{SU}^m(N)$. In addition there are twelve Weyl fermions ("quarks") which belong to $\mathrm{SU}^e(N) \times \mathrm{SU}^m(N)$. The matter fields originate from distinct $\mathrm{SU}(N)$ groups.

Again, it is easy to see that the one loop beta function is zero. The proofs of [15, 19] guarantee that the theory is indeed finite.

These non-SUSY CFT's are new in the sense that they cannot be constructed by an orbifold of type IIB [14, 24].

7. Conclusions

In this paper we constructed various non-supersymmetric large N gauge theories which were suggested to share many properties of their supersymmetric parents. In particular, we found CFT's, a special version of Seiberg duality (which was considered first in [19]), a degenerate mass spectrum and a moduli space of vacua.

The construction of non-supersymmetric brane configurations suggests many directions of research. We didn't consider theories in higher or lower dimensions than four and we didn't consider branes in the presence of orientifolds (orientifolds of type 0 theories were discussed in [25]). It seems that many results which were obtained via type II brane configurations can be easily copied to the type 0 case.

Finally, we would like to refer the reader to phenomenological aspects of orbifold gauge theories [26]. It was argued that the standard model may be included in "$\mathcal{N} = 4$" like theories. This scenario suggests that the underlying theory is not supersymmetric but conformal.

Acknowledgments

We thank Ofer Aharony, Vadim Kaplunovsky, Arvind Rajaraman, Jacob Sonnenschein and Shimon Yankielowicz for useful discussions.

References

[1] A. Hanany and E. Witten, *Type IIB superstrings, BPS monopoles, and three-dimensional gauge dynamics*, *Nucl. Phys.* **B 492** (1997) 152 [`hep-th/9611230`].

[2] A. Giveon and D. Kutasov, *Brane dynamics and gauge theory*, `hep-th/9802067`.

[3] N. Seiberg and E. Witten, *Monopole condensation, and confinement in $N = 2$ supersymmetric Yang-Mills theory*, *Nucl. Phys.* **B 426** (1994) 19 [hep-th/9407087].

[4] E. Witten, *Solutions of four-dimensional field theories via m theory*, *Nucl. Phys.* **B 500** (1997) 3 [hep-th/9703166].

[5] N. Seiberg, *Electric-magnetic duality in supersymmetric non-abelian gauge theories*, *Nucl. Phys.* **B 435** (1995) 129 [hep-th/9411149].

[6] S. Elitzur, A. Giveon and D. Kutasov, *Branes and $N = 1$ duality in string theory*, *Phys. Lett.* **B 400** (1997) 269 [hep-th/9702014].

[7] S. Elitzur, A. Giveon, D. Kutasov, E. Rabinovici and A. Schwimmer, *Brane dynamics and N=1 supersymmetric gauge theory*, *Nucl. Phys.* **B 505** (1997) 202 [hep-th/9704104].

[8] I.R. Klebanov and A.A. Tseytlin, *D-branes and dual gauge theories in type 0 string theory*, *Nucl. Phys.* **B 546** (1999) 155 [hep-th/9811035].

[9] O. Bergman and M.R. Gaberdiel, *Dualities of type 0 strings*, hep-th/9906055.

[10] J.M. Maldacena, *The large N limit of superconformal field theories and supergravity*, *Adv. Theor. Math. Phys.* **2** (1998) 231 [hep-th/9711200];
S.S. Gubser, I.R. Klebanov and A.M. Polyakov, *Gauge theory correlators from non-critical string theory*, *Phys. Lett.* **B 428** (1998) 105 [hep-th/9802109];
E. Witten, *Anti de Sitter space and holography*, *Adv. Theor. Math. Phys.* **2** (1998) 253 [hep-th/9802150].

[11] I.R. Klebanov and A.A. Tseytlin, *A non-supersymmetric large N CFT from type 0 string theory*, *J. High Energy Phys.* **03** (1999) 015 [hep-th/9901101].

[12] J.A. Minahan, *Glueball mass spectra and other issues for supergravity duals of QCD models*, *J. High Energy Phys.* **01** (1999) 020 [hep-th/9811156];
G. Ferretti and D. Martelli, *On the construction of gauge theories from non critical type 0 strings*, hep-th/9811208;
I.R. Klebanov and A.A. Tseytlin, *Asymptotic freedom and infrared behavior in the type 0 string approach to gauge theory*, *Nucl. Phys.* **B 547** (1999) 143 [hep-th/9812089];
M.R. Garousi, *String scattering from D-branes in type 0 theories*, *Nucl. Phys.* **B 550** (1999) 225 [hep-th/9901085];
J.A. Minahan, *Asymptotic freedom and confinement from type 0 string theory*, *J. High Energy Phys.* **04** (1999) 007 [hep-th/9902074];
I.I. Kogan and G. Luzon, *Scale invariance of Dirac condition $g_e g_m = 1$ in type 0 string approach to gauge theory*, *Phys. Lett.* **B 457** (1999) 70 [hep-th/9902086];
M. Billo', B. Craps and F. Roose, *On D-branes in type 0 string theory*, *Phys. Lett.* **B 457** (1999) 61 [hep-th/9902196];
A. Armoni, E. Fuchs and J. Sonnenschein, *Confinement in 4D Yang-Mills theories from non-critical type 0 string theory*, *J. High Energy Phys.* **06** (1999) 027

[hep-th/9903090];
M.S. Costa, *Intersecting D-branes and black holes in type 0 string theory*, *J. High Energy Phys.* **04** (1999) 016 [hep-th/9903128];
M. Alishahiha, A. Brandhuber and Y. Oz, *Branes at singularities in type 0 string theory*, *J. High Energy Phys.* **05** (1999) 024 [hep-th/9903186];
G. Ferretti, J. Kalkkinen and D. Martelli, *Non-critical type 0 string theories and their field theory duals*, hep-th/9904013;
R. Blumenhagen, A. Font and D. Lust, *Tachyon-free orientifolds of type 0B strings in various dimensions*, hep-th/9904069.

[13] O. Bergman and M.R. Gaberdiel, *A non-supersymmetric open string theory and S-duality*, *Nucl. Phys.* **B 499** (1997) 183 [hep-th/9701137].

[14] S. Kachru and E. Silverstein, 4*d Conformal field theories and strings on orbifolds*, *Phys. Rev. Lett.* **80** (1998) 4855 [hep-th/9802183].

[15] M. Bershadsky and A. Johansen, *Large N limit of orbifold field theories*, *Nucl. Phys.* **B 536** (1998) 141 [hep-th/9803249].

[16] N. Nekrasov and S.L. Shatashvili, *On non-supersymmetric CFT in four dimensions*, hep-th/9902110.

[17] K. Zarembo, *Coleman-Weinberg mechanism and interaction of D3-branes in type 0 string theory*, hep-th/9901106.

[18] A.A. Tseytlin and K. Zarembo, *Effective potential in non-supersymmetric* $\mathrm{SU}(N) \times \mathrm{SU}(N)$ *gauge theory and interactions of type 0 D3-branes*, *Phys. Lett.* **B 457** (1999) 77 [hep-th/9902095].

[19] M. Schmaltz, *Duality of non-supersymmetric large N gauge theories*, *Phys. Rev.* **D 59** (1999) 105018 [hep-th/9805218].

[20] A. Hanany and A. Zaffaroni, *On the realization of chiral four-dimensional gauge theories using branes*, *J. High Energy Phys.* **05** (1998) 001 [hep-th/9801134].

[21] A. Hanany, M.J. Strassler and A.M. Uranga, *Finite theories and marginal operators on the brane*, *J. High Energy Phys.* **06** (1998) 011 [hep-th/9803086].

[22] M. Aganagic, A. Karch, D. Lust and A. Miemiec, *Mirror symmetries for brane configurations and branes at singularities*, hep-th/9903093.

[23] M. Bershadsky, Z. Kakushadze and C. Vafa, *String expansion as large N expansion of gauge theories*, *Nucl. Phys.* **B 523** (1998) 59 [hep-th/9803076].

[24] A. Lawrence, N. Nekrasov and C. Vafa, *On conformal theories in four dimensions*, *Nucl. Phys.* **B 533** (1998) 199 [hep-th/9803015].

[25] A. Sagnotti and M. Bianchi, *On the systematics of open string theories*, *Phys. Lett.* **B 247** (1990) 517;

A. Sagnotti, *Some properties of open string theories*, hep-th/9509080;
A. Sagnotti, *Surprises in open string perturbation theory*, *Nucl. Phys.* **56** *(Proc. Suppl.)* (1997) 332 [hep-th/9702093].

[26] P.H. Frampton and C. Vafa, *Conformal approach to particle phenomenology*, hep-th/9903226;
P.H. Frampton, *Conformality and gauge coupling unification*, hep-th/9905042;
C. Csaki, W. Skiba and J. Terning, *Beta functions of orbifold theories and the hierarchy problem*, hep-th/9906057.