British Open Journal of Advanced Physics
Vol. 1, No. 1, March 2015, pp. 1-5
Available online at http://borpub.com/Journals.php

Research article

The particle spectrum of heavy ion interactions and Type IIB string theory

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Abstract

High energy heavy ion interactions are considered. Emphasized that the final states of ion interactions may be classified with the help of string theory. The particle spectrum is determined with the help of duality of super-Yang-Mills to Type IIB string theory. This spectrum is comparable with the experimental data for heavy-ion collisions at high energies. For different types of internal spaces topological invariants are calculated and presented corresponding particle spectra.

Keywords: heavy-ion collisions, super-Yang-Mills theory, type IIB string theory, particle spectrum, topological invariants.

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Introduction

A large amount of final state particles are produced in high energy heavy ion interactions. One of the models for hadron-hadron scattering is FRITIOF [1], which is a string-dynamical hadronic model. The possible final states are the string states. The historical origins of string theory were an attempt to understand the structure of hadrons [2, 3]. However the theory encountered a number of obstacles. Some obvious difficulties involved the spectrum which invariably included massless vectors, scalars and tensor particles. Thus string theory was abandoned as a theory of hadrons and replaced by QCD.

The success of string theory in understanding Regge trajectories and quark confinement was understood in terms of an approximate string-like behavior of chromo-electric flux tubes. According to this view, hadronic strings are not the infinitely thin idealized objects of mathematical string theory but are thick tubes similar to the quantized flux lines in superconductors. The ideal string theory was delegated to the world of quantum gravity. However more recent developments [4] have suggested that an idealized form of string theory may exactly describe certain gauge theories which are similar to QCD [5, 6].

AdS/CFT correspondence and superconformal Yang-Mills theories

We will consider the problem from the modern AdS/CFT perspective. We argue that although hadrons should be thought of as ideal thin strings from the 5-dimensional bulk point of view, the 4-dimensional strings are a superposition of "fat" strings of different thickness. The large N limit of certain conformal field theories (CFT) can be described in terms of Anti de-Sitter (AdS) supergravity. In particular, the four-dimensional N = 4 supersymmetric SU(N) Yang-Mills theory formulated on M_4 is equivalent to Type IIB string theory on $AdS_5 x S^5$. The symmetry of the latter is SU(2,2) x SU(4) which is just the even subgroup of the SU(2,2|4) superalgebra. In addition to the N = 4 supersymmetry algebra SU(2,2|4), there also exist the superalgebras SU(2,2|2) and SU(2,2|1). Their even subgroups are SU(2,2) x U(2) and SU(2,2) x U(1), respectively, and they are realized by conformal field theories with less supersymmetries, namely, N = 2 and N = 1 superconformal Yang-Mills theories. Let's consider the representations of SU(2,2|4) group [7]:

$$D(1,0,0\,|\,6)_0 + D\left(\frac{3}{2},\frac{1}{2},0\,|\,4\right)_2 + D\left(\frac{3}{2},0,\frac{1}{2}\,|\,\bar{4}\right)_2 + D(2,1,0\,|\,1)_2 + D(2,0,1\,|\,1)_2,$$

$$D(4,1,1\,|\,1)_0 + D\left(\frac{7}{2},1,\frac{1}{2}\,|\,\bar{4}\right)_2 + D\left(\frac{7}{2},\frac{1}{2},1\,|\,4\right)_2 + D\left(3,\frac{1}{2},\frac{1}{2}\,|\,15\right)_1 + D(3,1,0\,|\,6)_2$$

$$+ D(3,0,1\,|\,\bar{6})_2 + D\left(\frac{7}{2},\frac{1}{2},0\,|\,4\right)_2 + D\left(\frac{7}{2},0,\frac{1}{2}\,|\,\bar{4}\right)_2 + D\left(\frac{5}{2},\frac{1}{2},0\,|\,20\right)_2 + D\left(\frac{5}{2},0,\frac{1}{2}\,|\,\overline{20}\right)_2$$

$$+ D(2,0,0\,|\,20)_0 + D(3,0,0\,|\,10)_0 + D(3,0,0\,|\,\overline{10})_0 + D(4,0,0\,|\,1)_0 + D(4,0,0\,|\,1)_0\ .$$

Among multiplets $D(\Delta, J_1, J_2\,|\,N)_q$ we have 15-plet of vector mesons $D\left(3,\frac{1}{2},\frac{1}{2}\,|\,15\right)_1$ and 20-plet of baryons $D\left(\frac{5}{2},\frac{1}{2},0\,|\,20\right)_2$. Weight diagrams of these multiplets are represented in figure 1.

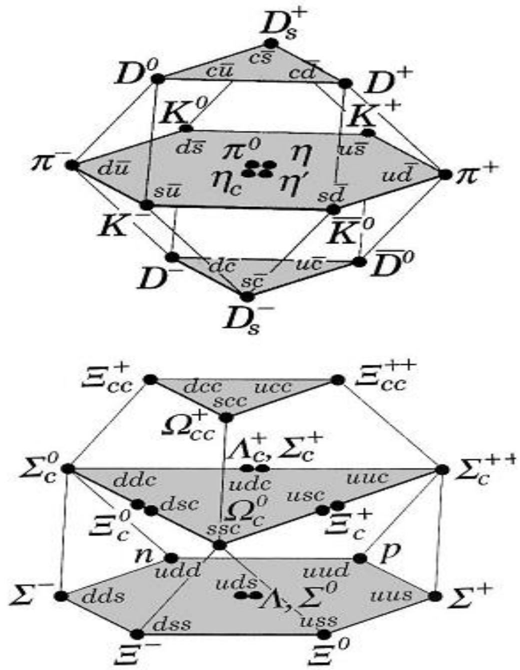

Fig. 1. Weight diagrams of vector mesons and baryons

Particle spectrum of orbifolded theory

The supergravity interpretation of even subgroups is chiral supergravity on AdS_5 x S/Γ where Γ is a discrete subgroup of SU(2) and SU(3) for the N = 2 and N = 1 cases, respectively. If, in particular, Γ is not in SU(3), then we get a non-supersymmetry theory. However in all these cases orbifolds of type IIB on AdS_5 x S^5 preserve the AdS structure but break some of the supersymmetries. Then the SU(2,2) symmetry of the AdS space should translate into a superconformal group on the orbifolded theory. In string theory unlike a supergravity point of view, orbifolds are not singular and we can study them reliably.

As soon as we are speaking about the internal space, it would be interesting to classify the manifolds by invariants. For this purpose we must consider most general notion of mathematical spaces - topological spaces. Being so general, topological spaces are a central unifying notion. Topological spaces with differing homotopy groups are never equivalent. For recording information about the basic shape, or holes of the topological space it is necessary to calculate the fundamental group of the corresponding space. Therefore, the information about the smoothness of space is encoded in the fundamental group of the corresponding space.

Let us consider the theory on N=4 Type IIB D3 branes at the Z_k orbifold singularity. Such gauge theories are realized in the world-volume of parallel Type IIB D3-branes, which spans the four spacetime coordinates of Minkowski space. The group Z_k acts only on the S^5 while leaving the AdS_5 untouched. The resulting spacetime still has an AdS_5 factor. After orbifolding the D3 brane theory must have an SO(4,2) conformal invariance. There the orbifold will act freely on the S^5 factor.

Kachru and Silverstein [8] suggested that if one studies N D3-branes on various orbifolds of R^6 and follows the conjecture of [9], then one is studying an orbifold of AdS_5 x S^5, where the orbifold group acts only on the S^5 factor. The conformal group of the field theory is identified with the isometry group of AdS_5 and, therefore, these orbifolds will lead to CFT on the D3-branes.

In the following we will consider D3 branes on some singularities and calculate the fundamental group for these cases. Knowing that AdS_5 is identified with the usual Minkowski spacetime, we will work with the internal space S^5 and calculate topological invariants for different orbifold groups. When the internal space has nontrivial fundamental group, the gauge group of the field theory is broken. After symmetry breaking it's interesting to consider the spectra of the three models presented below:

1) let us consider the internal space S^5/Z_3. Its fundamental group $\pi_1(S^5/Z_3) = Z_3$ and, therefore, this space is not smooth and has holes. We have orbifold singularities of the form $R^6/\Gamma = Z_3$ (with Γ a finite abelian group) or C^3/Z_3. The spectrum of this theory is considered in [10].

2) let us consider the nonsupersymmetric theories [8] with internal space S^5/Z_5. Its fundamental group $\pi_1(S^5/Z_5) = Z_5$ and, therefore, this space is not equivalent to the previous one. It is really so, because this theory is not supersymmetric at the level of the spectrum, even before considering interactions;

3) let us consider the theories with internal space $S^5/(Z_k \times Z_{k'})$. Its fundamental group $\pi_1(S^5/(Z_k \times Z_{k'})) = Z_k \times Z_{k'}$. The superpotential terms are of the same general form as for the first case [11], but the resulting spectra are rather lengthy to list.

Conclusion

We have used the fact that the large N limit of conformal field theories includes a sector describing supergravity on the product of Anti-de Sitter spacetimes and spheres. We also used the conjecture that Type IIB string theory on AdS_5 x S^5 is dual to N=4 super-Yang-Mills theory [9]. Since the isometry group of space is the subgroup of supergroup SU(2,2|4), whose representations are multiplets of mesons and baryons, they can be observed in experiments with heavy ion collisions [12]. We have explained that by orbifolding D3-branes in type IIB string theory, we should produce conformal field theories with different spectra for the three models. The nonsupersymmetric case is of particular interest because of cosmological constant problem. We calculated fundamental groups for three internal spaces and find that they are not smooth and not equivalent to each other.

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