Nuclear interactions in a Hologram

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1. Introduction

Some fundamental particles spin like tops. The laws that govern how they form nucleons, atoms and so forth depends on this spin. Incorporating spin in our mathematical models is important, with these models we try to calculate some quantities to compare with the measures taken from new experiments. Here I describe a new attempt to do this with a technique called holography.

2. Particles are Chiral

- Particles can spin in two ways relative to their motion. Right handed "helicity" is seen if the thumb of your right hand points in the direction of the particles movement, and your fingers wrap in the direction of the spin.
- If you need your left hand to match the spin direction the particle has left handed helicity.
- We also say that a particle can have left- or right-handed "chirality". For massless particles chirality and helicity are the same property.
- Chirality tells us how the wave that represents the particle changes. When we apply a transformation to the particle, its quantum wave-function is shifted in a way that depends on the particle's chirality.
- The strong interactions treat these two chirality states as different particles.

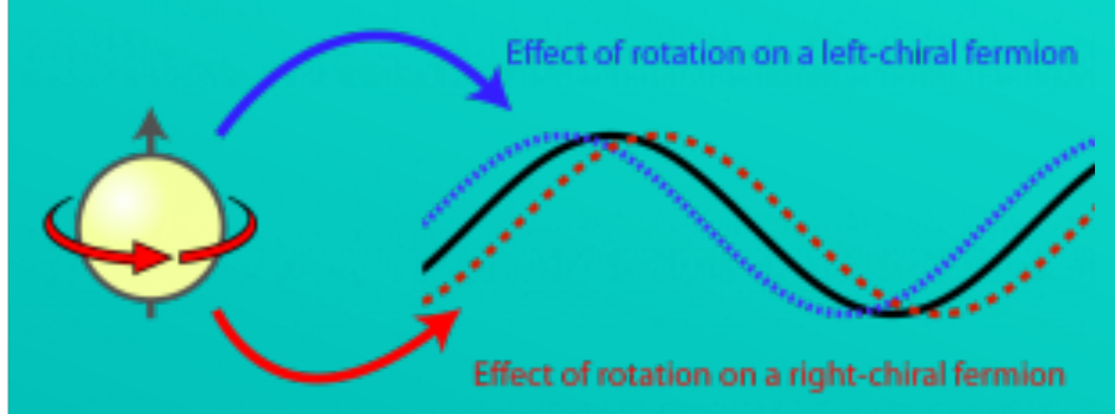

Illustration: Reference [2]

3. Holographic Principle

The idea of duality is that two very different looking theories can in fact describe the same physics. The two theories don't even have to have the same number of dimensions; one can be a "hologram" of the other. In the AdS/CFT correspondence Strings are thought of as "printed" like a hologram on the 4-D boundary of a 5-D space-time.

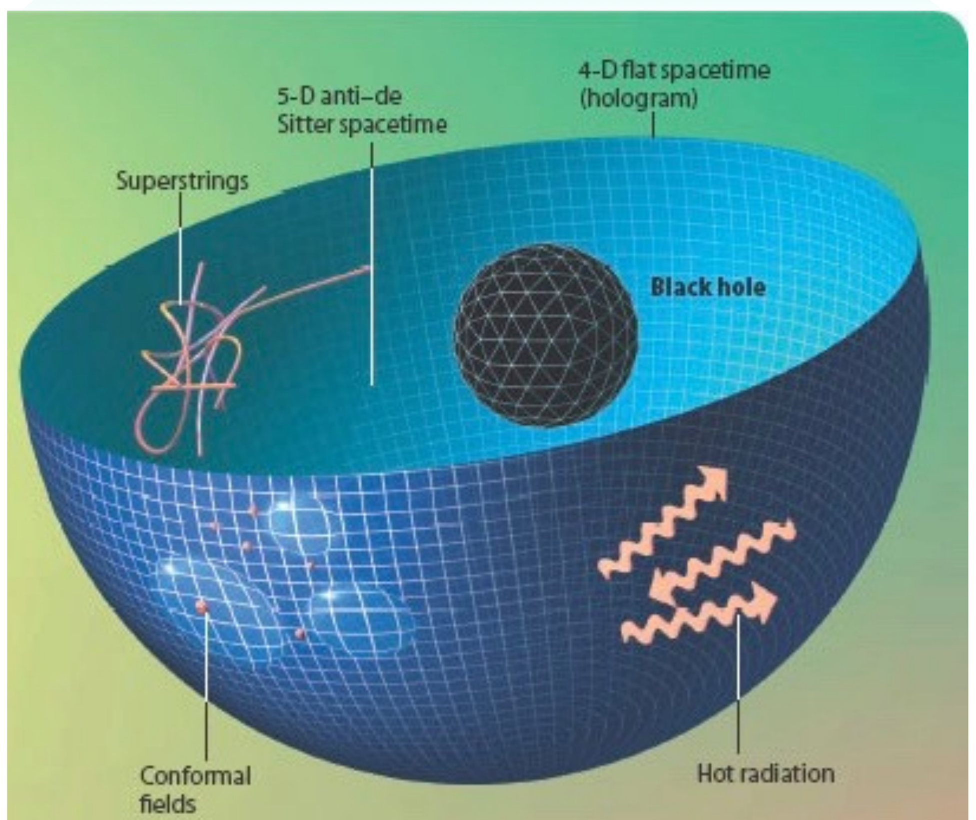

Illustration: Scientific American sp 17, 66 - 73 (2007)

4. Not only strings in String Theory

- While working out how strings move in the 10-D spacetime, it was found out that some of them move as if were attached to membranes of different dimension called D-branes.
- Some of the strings attached to D-branes, if we see them from far far away, have all the properties of the particles responsible for the fundamental forces, for example the Photon for the electromagnetic interactions.
- D3-Branes are important since it's because of them that the AdS/CFT correspondence could be established.

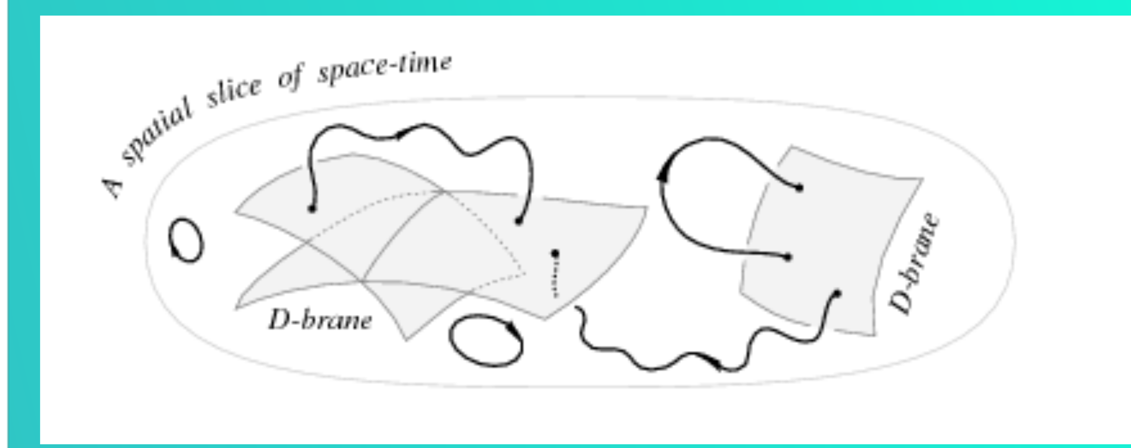

Illustration: arXiv:1112.4317v1

5. Holographic Quarks

- Quarks are the fundamental particles that form the nucleus of atoms.
- In the holographic correspondence one start with a large number of D3-branes to have a dual quantum theory that contains the particle responsible for the strong nuclear force.
- To add quarks to our theory we need new types of D-branes (flavour branes) in addition to the pack of D3 branes.
- Elemental particles appear in String Theory as different vibrations of the strings. Vibration of strings connecting a D3-brane and a flavour brane generate quarks.
- If the flavour branes are separated from the D3-branes, then this separation can be used as a energy scale in the theory, then the quarks are massive (Remember $E=mc^2$).

6. My Research

The focus of my research consist of studying the breaking of the symmetry between left handed and right handed quarks and to model how they bound to form particles called mesons.

I study this holographically, which means that I use a mathematical conjectured duality, the AdS/CFT correspondence that allows me to calculate quantities in quantum mechanics in 4 dimensions by working in a classical theory with only gravity in 5 dimensions, and then translate the answer to the quantum side with help of a established "dictionary".

Specifically I am working to obtain the behavior of mesons by studying small perturbations of the flavour D-branes and using the idea of domain walls quarks proposed by Kaplan [3] to obtain chiral particles.

To understand what are domain walls particles consider a 3D space (x, y, z) then we take the particles to have a mass which is constant but switches sign at y = 0. It can be shown that a massless mode exists bound to the plane y=0 , and that it is chiral: there exist a right hand mode, but not a left hand one.

We implemented this idea in the well known D3/D7 model, and we found the correct behaviour at small distances for the small fluctuations of the flavour brane dual to mesons. We also found massless mesons localized where the mass changes sign. We now are starting to study the D4/D8 model where we wrap one dimension of the D4 branes in a circle with small radius. It is in this compactified dimension in which we want the mass of the particles to change sign.

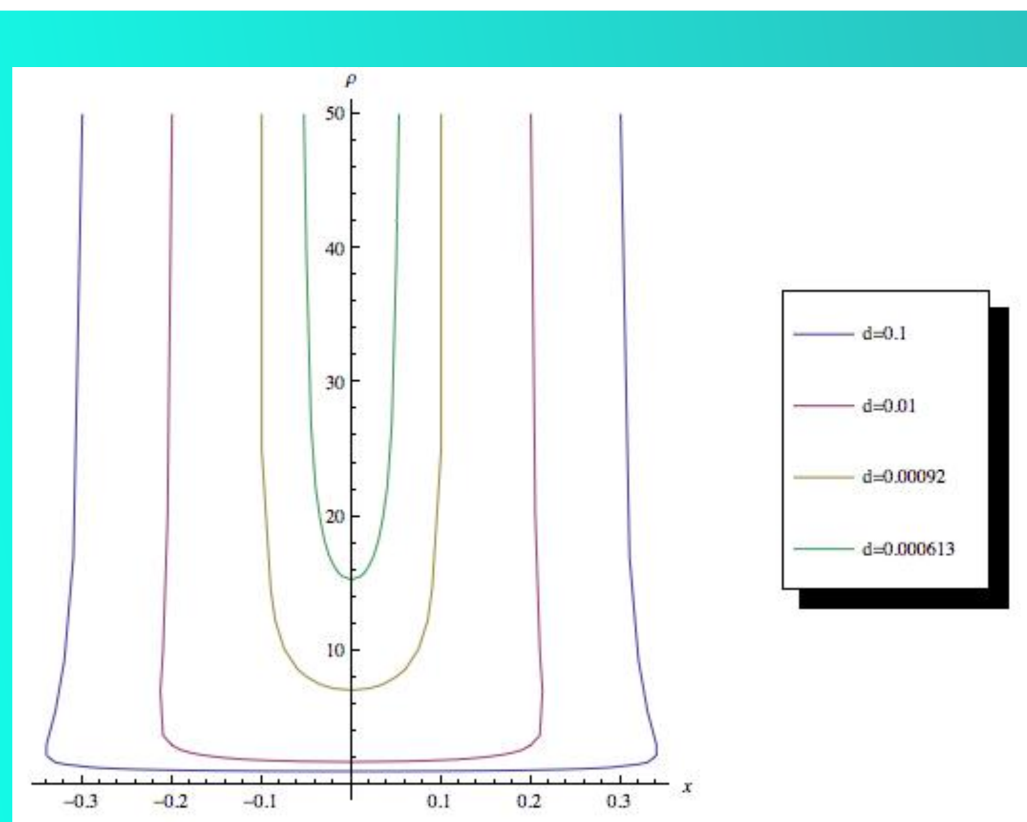

Illustration: Massless mesons localized in the (x, ρ) plane. Jesus Cruz Rojas (2017)

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[1] J. Erdmenger, N. Evans, I. Kirsch, and E. J. Threlfall. Mesons in gauge/gravity duals. *The European Physical Journal* A, 35(1):81–133, Jan 2008
[2] http://www.quantumdiaries.org/2011/06/19/helicity-chirality-mass-and-the-higgs/
[3] arXiv:0912.2560v2

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