Instituto de Física y Astronomía
Facultad de Ciencias, Universidad de Valparaíso, Chile.

Dirección: Av. Gran Bretaña 1111, Playa Ancha, Valparaíso, Chile.
Teléfono: +56 32 2508426

Vector and baryon spectra via holography in an AdS deformed background

Miguel Ángel Martín Contreras
With A. Vega, E. Folco-Cappssoli, Danning Li, and H. Boschi-Filho

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Instituto de Física y Astronomía, Universidad de Valparaíso, Chile

Outline

AdS/CFT: in a nano-nutshell

AdS/CFT establishes an equivalence between non-perturbative QFT and Gravity.

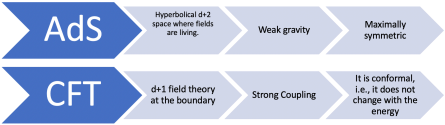

Figure 1: AdS/CFT

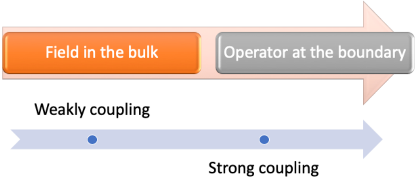

Figure 2: Field/Operator duality

But this QFT, in the first approximation, is conformal.
Real world is far away from conformal!!!

AdS and Confinement

For example, the existence of confinement: for some energies, hadrons are bounded. For others, they break apart.

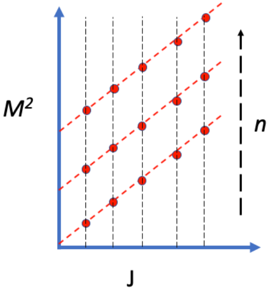

Figure 3: Regge Trajectory

One evidence of the presence of confinement is the Regge Trajectories.

These trajectories can be defined as *a systematic form to organize hadronic states according to their angular momentum and excitation level.* (See Prof. S. Afonin's talk).

AdS and Confinement in the bottom-up approach

Bottom-up in this holographic context means *fixing the gravity and background fields to mimic the QFT properties*. If we said that this QFT is QCD, we call this approach, *AdS/QCD* (See Prof. A. Vega's talk).

Since AdS does not have an energy scale (so, there is no confinement in such geometry), we need to introduce one. This extra energy scale will induce confinement and as a consequence, the normalizable of the fields living in AdS will have a spectrum.

If we do the the identification of these normalizable states with hadrons, we can construct Regge trajectories. This is the key point!.

AdS and Confinement

In these bottom-up approaches, confinement is realized via the breaking of the conformal symmetry. This can be done in many forms. For example:

- explicitly, by introducing a cutoff to the AdS/Space. This is the hardwall model (Braga and Boshi-Filho, 2005, Polchinski-Strassler 2006).
- softly by introducing a smooth quadratic and static dilaton field (Karch et. al. 2006).
- mixing both approaches: a UV cutoff and a static and quadratic dilaton (Braga, M.A. Martin and Diles, 2014).

This leads us to conclude that we can induce confinement by:

- Deforming the AdS background.
- Introducing a proper dilaton field.

How we construct hadrons: Hadronic Identity

Hadrons are characterized by its scaling dimension, that is fixed to be the conformal one, Δ, for the bulk fields. According to the original AdS/CFT, the bulk mass M_5 carries the information Δ as follows:

- Mesons with $\Delta = 3$:

$$M_5^2 R^2 = (\Delta - S)(\Delta + S - 4) \tag{1}$$

- Baryons of spin $1/2$ with $\Delta = 3/2$:

$$m_5 = \Delta + 2. \tag{2}$$

Thus, the bulk mass defines the *hadronic identity* of the state at hand.

Holographic algorithm

- Define a geometry background.
- Define an action for the bulk fields dual to hadronic states.
- Obtain equations of motion.
- Solve the associated Sturm-Liouville problem (Boundary Value Problem).
- Find the mass spectrum as the eigenvalues of the BVP.
- Evaluate the Regge Trajectory.

AdS deformed Background

First consider a geometric background given by following the line-element:

$$dS^2 = e^{2(z)} \left[dz^2 + \eta_{\mu\nu} \, dx^\mu \, dx^\nu \right], \quad (3)$$

where $\eta_{\mu\nu}$ is a 4-dimensional Minkowski tensor. Since we want AdS-like geometries, we will impose that the warp factor behaves as

$$A(z) = \log\left(\frac{R}{z}\right) + \frac{1}{2} k \, z^2 \quad (4)$$

such that, at the conformal boundary $z \to 0$, we recover the usual AdS Poincare patch.

Hadronic States in the AdS deformed background

Hadronic states will be given by fields living in this background. For each specie we can construct an action of the form

$$I = \frac{1}{\mathcal{K}} \int d^5x \sqrt{-g}\, \mathcal{L}_{\text{Hadron}} \tag{5}$$

with $\mathcal{L}_{\text{Hadron}}$ given by:

$$\mathcal{L}_V = -\frac{1}{4\, g_V^2}\, g^{m\,r}\, g^{n\,p}\, F_{mn}\, F_{rp} - \frac{1}{2}\, M_{5,V}^2\, g^{m\,n}\, A_m\, A_n, \tag{6}$$

$$\mathcal{L}_S = -\frac{1}{2\, g_S^2}\, g^{m\,n}\, \partial_m S\, \partial_n S - M_{5,S}^2\, S^2, \tag{7}$$

$$\mathcal{L}_B = \bar{\Psi}\left[\Gamma^m\, \partial_m - M_{5,B}\right] \Psi. \tag{8}$$

Equations of motion

From the action for the bulk field we obtain:

- for mesons with $\beta = -3 + 2\,S$:

$$\partial_z \left[e^{\beta\, A(z)} \partial_z\, \psi(z,q) \right] + (-q^2) e^{\beta\, A(z)}\, \psi(z,q) - M_{5,\beta}^2\, e^{(\beta+2)\, A(z)}\, \psi(z,q) = 0. \quad (9)$$

- for baryons

$$\psi_-'' + 4\, A'\, \psi_-' + \left[4\, A'^2 + 2\, A'' - m_5\, A'\, e^{A} - m_5^2\, e^{2\, A} \right] \psi_- + (-q^2)\, \psi_- = 0 \quad (10)$$

where $\Psi(z,q) = \psi_+(z,q) + \psi_-(z,q)$.

From these equations, fixing the bulk mass ($M_{5,\beta}$ for mesons and m_5 for baryons) we can construct the mass spectrum by solving the BVP.

Parameter fixing

For the numerical calculation, the parameter choice was defined as:

Hadronic state	Bulk mass	β	k (GeV^2)
Vector	0	-1	-0.613^2
Scalar	-3	-3	-0.332^2
1/2 baryon	5/2	X	0.205^2

Spin 1/2 *baryons*

In the case of spin 1/2 baryons we obtain the following results:

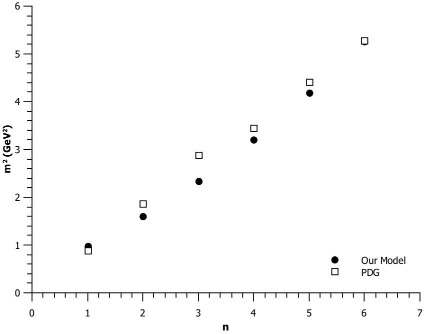

Figure 4: $N(1/2^+)$ radial trajectory obtained with the deformed AdS_5 space approach (dots) and PDG data (squares).

Spin 1/2 *baryons*

In this case the radial Regge trajectories for both cases, experimental and theoretical data, are given by

$$m^2_{Exp} = (0.863 \pm 0.029)\, n + (0.114 \pm 0.111)\,, \tag{11}$$
$$m^2_{th} = (0.860 \pm 0.042)\, n - (0.081 \pm 0.164)\,. \tag{12}$$

with a RMS error of 4.1%.

Higher fermionic spin baryons

The high 1/2 spin equation for fermions has the same estructure as the Sturm–Liouville that we had obtained for the nucleon case. Thus, we can use the same equation but changing the bulk mass m_5 since the conformal dimension of the operator that creates these hadrons has a different dimension. We will discuss the 3/2 and 5/2 cases.
The parameters in these cases are:

Hadronic state	Bulk mass	k (GeV^2)
3/2	7/2	0.190^2
5/2	13/2	0.205^2

High spin 1/2 *results*

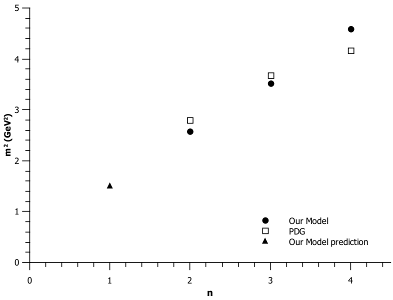

Figure 5: $N(3/2^{+})$ baryon radial trajectory obtained within the deformed AdS_5 space approach (dots) vs PDG (squares).

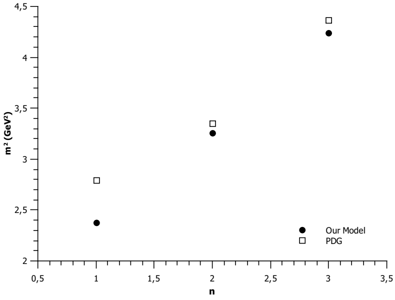

Figure 6: $N(5/2^{+})$ baryon radial trajectory obtained within the deformed AdS_5 space approach (dots) vs PDG (squares).

High spin 1/2 *results*

For the $N(3/2^+)$, the experimental and theoretical trajectories are

$$m^2_{Exp} = (0.678 \pm 0.117)\, n + (1.517 \pm 0.364)\,, \quad (13)$$

$$m^2_{th} = (1.021 \pm 0.017)\, n + (0.501 \pm 0.047)\,. \quad (14)$$

with an RMS error of 9%.
For the $N(5/2^+)$ we obtain

$$m^2_{Exp} = (0.785 \pm 0.135)\, n + (1.934 \pm 0.291)\,, \quad (15)$$

$$m^2_{th} = (0.931 \pm 0.031)\, n + (1.429 \pm 0.068)\,. \quad (16)$$

with an RMS error of 2.76%.

Light Vector Mesons

In the case of light vector mesons, we obtain the following results:

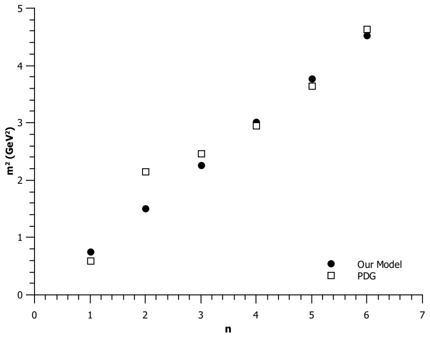

Figure 7: Vector meson ρ radial trajectory obtained with the deformed AdS_5 space approach (dots) Vs PDG (squares)

Light Vector Mesons

In this case, the radial Regge trajectories are fitted as:

$$m^2_{Exp} = (0.720 \pm 0.076)\, n - (0.223 \pm 0.302)\,, \quad (17)$$

$$m^2_{th} = (0.754 \pm 8 \times 10^{-7})\, n\,. \quad (18)$$

With a RMS error of 7.8%.

Light Scalar mesons

In the case of scalar mesons we obtain the following results:

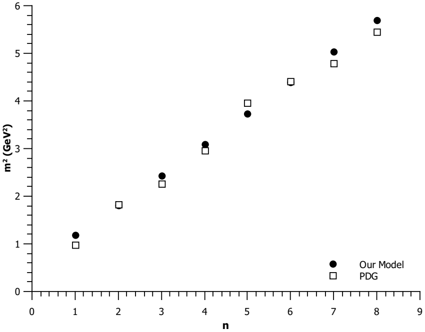

Figure 8: Scalar meson f_0 radial trajectory obtained with the deformed AdS_5 space approach (dots) vs PDG (squares).

Light Scalar Mesons

In this case, radial Regge trajectories can be fitted to be:

$$m^2_{Exp} = (1.314 \pm 0.017)\, n_r - (0.285 \pm 0.332)\,, \qquad (19)$$

$$m^2_{th} = (1.288 \pm 0.009)\, n_r - (0.117 \pm 0.024)\,. \qquad (20)$$

With an RMS error of 3.8%.

Final Comments

Summary of Results

- Notice that these states were constructed with $L = 0$ as a first approximation. So we do not fit father and daughter trajectories.
- Confinement can be realized via background deformations.
- Hadronic states were constructed as deformations of the AdS space with an RMS error near to 12%. Each hadronic specie has its own background since it depends on the value of k.

Things to do

- To extend this formalism to other hadronic states, as exotic or hybrid mesons.
- To graduate the model to a single background for all the hadronic species in order to explore other hadronic properties as the form factors and structure functions.

Thank you!