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The graviton soft-wall model and the descriptions of mesons and exotic states

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In this contribution, the main results of the calculations of different hadron properties, obtained within of the holographic graviton soft-wall model have been presented. In particular, the glueball, regular meson and hybrid spectra have been shown. Results are in fair agreement with experimental data, when available, and with lattice analyses. Moreover, the model has been improved to take into account the chiral-symmetry breaking mechanism to properly describe the pion within this framework.

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1. Introduction

In this talk, the main outcomes of the our studies on meson and glueball spectra within the graviton soft-wall (GSW) model [1–4] have been discussed. Holographic approaches rely on a correspondence between a five dimensional classical theory with an AdS metric and a supersymmetric conformal quantum field theory. Since the latter is not QCD, further modifications and improvements need to be implemented to describe non-perturbative properties of QCD [5, 6]. In the GSW model, the original soft-wall (SW) metric is properly modified to describe the glueball spectrum as a graviton propagating in this space. We also studied the spectra of light, heavy and hybrid mesons. Results have been obtained by using only two fixed parameters and are in good agreement with data and lattice analyses. The model has been also properly modified to describe the pion spectrum and its static properties [7].

2. The Graviton Soft-Wall model

The GSW model can be considered a modification of the usual SW one. In this case, the background metric of the theory in the gravity sector, is:

$$ds^2 = e^{\alpha k^2 z^2} g_{MN} dx^M dx^N = e^{\alpha k^2 z^2} \frac{R^2}{z^2} \left(\eta_{\mu\nu} dx^\mu dx^\nu - dz^2\right) \tag{1}$$

where g_{MN} is the usual AdS_5 metric used in the SW model [1, 8, 9]. Similar approaches of the GSW one can be found in, e.g., Refs. [9, 10]. The confinement mechanism for mesons is realized through a dilaton:

$$\bar{S} = \int d^5x e^{\phi_0(z)} \sqrt{-g} \mathcal{L}(x_\mu, z) \ . \tag{2}$$

where $\mathcal{L}$ is the lagrangian density of the propagating field, dual to the QCD state, in the space and ϕ_0 is the profile function of the dilaton responsible for the confinement mechanism.

3. The glueball spectra within the GSW model

In our model [1] we calculated the spectrum of the scalar glueball from that of a graviton propagating in the space Eq. (1). The potential is uniquely determined by the modified metric and the only free parameter is the scale factor $\alpha k^2 \sim (0.37\ \mathrm{GeV})^2$ fixed from the comparison with lattice QCD. As one can see in the left panel of Fig. 1, the linear glueball spectrum is well reproduced. The predicted ground state is in agreement with the BESIII data of the J/Ψ decays [11]. The model [3] also reproduces the lattice predictions of the Regge trajectories for even and o odd glueball spin [12, 13] if we consider the approach of Refs. [9, 14] to describe the spin dependent spectrum of glueballs.

4. The spectra of scalar and pseudo-scalar mesons

For scalar mesons the action in the gravity sector is:

$$\bar{S} = \int d^5x \sqrt{-g} e^{-k^2 z^2 - \phi_n} \left[g^{MN} \partial_M S(x) \partial_N S(x) + e^{\alpha k^2 z^2} M_5^2 R^2 S(x) \right] , \tag{3}$$

with $M_5^2R^2 = -3$ (-4) for light mesons (pseudo-scalar mesons), and ϕ_n an additional dilaton (not including further free parameters) which leads to bound state [2]. By keeping fixed $\alpha k^2 = 0.37$ GeV^2, we found a reasonable good fit, see in Fig. 1, for $0.51 \leq \alpha \leq 0.59$. For heavy mesons we added the quark mass contribution to the light scalar masses [2, 3] in order to effectively include the heavy quark mass dynamics. The successful comparison with data [3] is displayed in the right panels of Fig. 1. In Ref. [4], the spectra of hybrid mesons have been calculated. In this case, for example, $M_5^2R^2 = 5$ for 0^{-+} or $M_5^2R^2 = 12$ for 0^{+-} states. Results are in good agreement with lattice data, see Table. 1.

5. Vector states

For a vector field one can assume the following action

$$\bar{S} = -\frac{1}{2}\int d^5x\sqrt{-g}e^{-k^2z^2-\phi_n}\left[\frac{1}{2}g^{MP}g^{QN}F_{MN}F^{PQ}M_5^2R^2g^{PM}A_PA_Me^{\alpha k^2z^2}\right]. \qquad (4)$$

Here $M_5^2R^2 = -1$ for a_1 and $M_5^2R^2 = 0$ for ρ mesons, respectively [15]. Given the above parameters, we get the spectrum shown in the (a) and (b) panels of Fig.2. Our calculation favors that the $a_1(1930)$, $a_1(2095)$ and $a_1(2270)$ are axial resonances. In the case of the ρ, the agreement is good, exception is $\rho(770)$. Also in this case, for hybrids, the main difference with regular mesons is the value of $M_5^2R^2$. For example: $M_5^2R^2 = 8$ (for 1^{--} and 1^{-+} states) and $M_5^2R^2 = 15$ (for 1^{++} and 1^{+-} states). Results are displayed in Table 1.

6. The pion structure

In order to describe the pion structure, the GSW model has been modified to incorporate the chiral symmetry breaking mechanism. Details can be found in Ref. [7]. Two further free parameters are requested: γ_π and the quark mass m_q. We proposed two ansatz: $\gamma_\pi = -0.6$ (-0.17) and $m_q = 45$ (52) MeV called GSWL1 (GSWL2). Both parametrizations lead to very good description of, e.g., the spectrum, the decay constant and the mean pion radius [7]. In Fig. 2 we show, for example, the calculations of the form factor (FF). As one can see very good agreements have been found.

7. Conclusions

In this contribution we presented the main predictions of the GSW model. A several amount of experimental data of different observables for different hadrons have been described with few fixed parameters. For the pion, the model has been modified and also in this case the comparison with data is quite good. We conclude by remarking the predicting power of the model.

Acknowledgments

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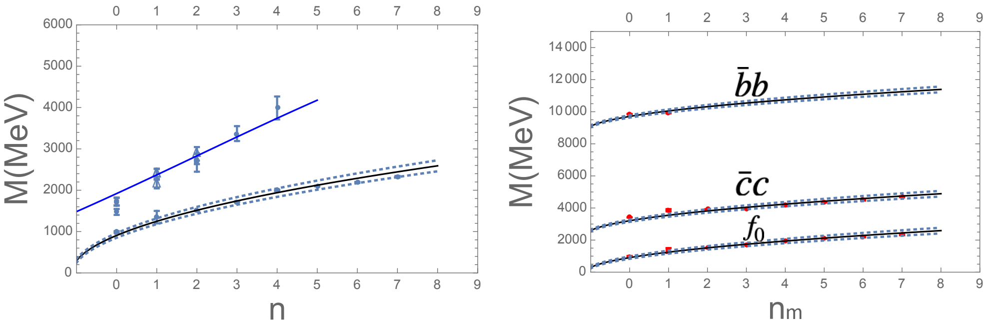
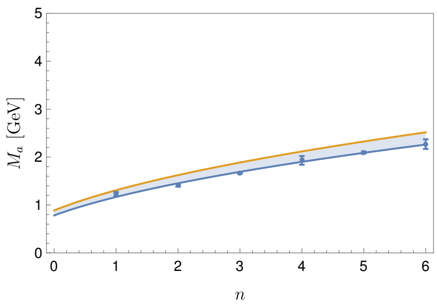
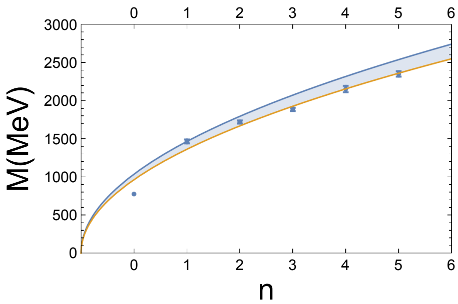


Figure 1: *Left panel*: *GSW fit to the scalar lattice glueball spectrum and to the experimental scalar meson spectrum. Right panel*: *The scalar meson spectrum GSW fit to the data shown for all quark sectors. Data included in Refs.* [1, 3].



(a)



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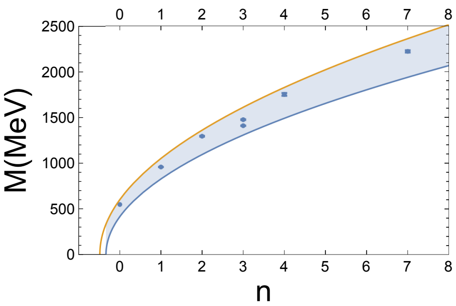

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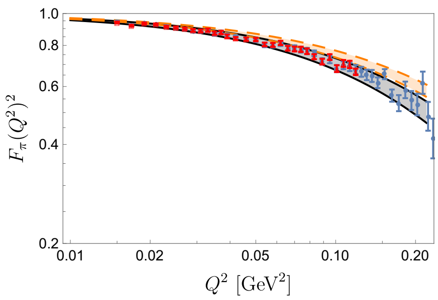

(d)

Figure 2: (a): the a_1 spectrum. (b): The ρ mass plot as a function of mode number. (c): the η spectrum. (d): The pion FF. Full line for GSWL2 and the dashed one for GSWL1. All data included in Refs. [2, 7]

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	LQCD 1	LQCD 2	GSW
0^{-+}	-	2.1	2.074 ± 0.028
0^{++}	1.98	>2.4	2.694 ± 0.021
1^{--}	0.87	2.3	2.149 ± 0.017
1^{+-}	1.25	>2.4	2.747 ± 0.013
1^{++}	-	>2.4	2.747 ± 0.013
0^{+-}	-	>2.4	2.694 ± 0.021
1^{-+}	2.15	2.0	2.149 ± 0.017

Table 1: Hybrid spectra evaluated within the GSW model. References to lattice data can be found in Ref. [4].

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