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MESON-NUCLEON COUPLING CONSTANT FROM THE ADS/QCD MODELS

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Abstract

In the framework of the hard wall and soft wall models of AdS/QCD we calculated the meson nucleon coupling constant. The interaction Lagrangian between vector, pseudoscalar and spinor fields was used in the bulk of AdS space. Using the AdS/CFT correspondence an integral expression was found for the meson nucleon coupling constant and its numerical value was calculated.

Keywords: *AdS /QCD, meson, nucleon, coupling constant.*

1. Introduction. The AdS/CFT duality is an idea which originated from superstring theory. Superstring theory is the prime candidate of the unified theory which unify four fundamental forces in nature, namely gravity, the electromagnetic force, the weak force and the strong forces. Thus, the AdS/CFT duality claims equivalence between two theories: Strongly –coupled 4-dimensional gauge theory and Gravitational theory in 5-dimensional AdS spacetime. AdS/CFT is often called a holographic theory.

The anti-de-Sitter space is a maximally symmetric, homogenous and isotropic space-time with constant negative curvature.

Holographic QCD aims to study strongly coupled regime of QCD using AdS/CFT to get analytical model for hadron structure and their interactions. There are two approaches for to calculate coupling constant in AdS/QCD

1. Hard wall model-The lagrangian is multiplied by a step function so that it vanishes beyond.
2. Soft wall model-Introduce an additional field called dilaton field that breaks the scale symmetry. The lagranjian is multiplied by $e^{-D(z)}$, so that it vanishes slowly as z increases.

2. Scalar field responsible for the chiral symmetry breaking. Action for the scalar X field is as below in the five dimensional space-time:

$$S=\int d^5x\sqrt{G}Tr[|DX|^2+3|X|^2] \tag{2.1}$$

Covariant derivative D_M is defined as below:

$$D_M=\partial_M X-iA_L^M X+XA_R^M$$

The X field is written in the form:

$$X=v(z)exp\left[i\sqrt{2}\pi^a\sigma^a\right],$$

where the π^a field in the dual QCD describe pions. From the action (2.1) for $v(z)$ has a form

$$v(z)\approx\frac{1}{2}am_q z+\frac{1}{2a}\sigma z^3, \tag{2.2}$$

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which is corrected by a and $1/a$ factors ($a = \sqrt{N_c}/(2\pi)$). In the earlier works [6] in the calculation of the $g_{\rho NN}^{(1)nm}$ and f_{ρ}^{nm} constants the factor a in the profile function (2.2) was not taken into account. The coefficient m_q is the mass of u and d quarks and σ were established from the UV and IR boundary conditions imposed on the solution for the field.

3. Profile functions for fields in the hard-wall and soft-wall models. We recall the profile functions of different fields in the hard and soft –wall models. In hard wall model the profile function for the vector field is expressed in terms of Bessel function [6]:

$$V(z) = \frac{zJ_1(m_\rho z)}{\sqrt{\int_0^{z_m} dzz\left[J_1(m_\rho z)\right]^2}}, \tag{3.1}$$

where m_ρ is the mass of the rho meson. Fermion fields profile functions are expressed in terms of Bessel functions of first kind [5,1,6,7]

$$F_{1L}^{n} = C\, z^{\frac{5}{2}} J_2(pz), \qquad F_{1R}^{n} = C z^{\frac{5}{2}} J_3(pz), \tag{3.2}$$

where the boundary fermions were taken on mass-shell $|p| = M_n$. As is seen from (3.2) $F_{1L,R}$ and $F_{2L,R}$ are related one another

$$F_{1L} = F_{2R}, \qquad F_{1R} = -F_{2L}.$$

The normalization constant was found in [9] and is equal to

$$|C_{1,2}^{n}| = \frac{\sqrt{2}}{z_m J_2(m_n z_m)}. \tag{3.3}$$

Kaluza Klein mass spectrum M_n of excited states, which is expressed in terms zeros $\alpha_n^{(m)}$ of the Bessel functions J_m :

$$M_n = \frac{\alpha_n^{(5)}}{z_m} \tag{3.4}$$

Thus, the mass spectrum is determined by value of z_m which is free parameter of the model.

In the soft-wall the profile function for the n -th normalized Kaluza-Klein mode of spinor field is expressed in terms of Laguerre polynomials L_n^{α} [2,8]:

$$F_{1L}^{n}(z) = n_{1L}\, (kz)^{2\alpha} L_n^{(\alpha)}(kz),$$
$$F_{1R}^{n}(z) = n_{1R}\, (kz)^{2\alpha-1} L_n^{(\alpha-1)}(kz). \tag{3.5}$$

The constants $n_{L,R}$ are found from the normalization condition and are equal to following ones [8,9]:

$$n_{1L} = \frac{1}{k^{\alpha-1}} \sqrt{\frac{2\Gamma(n+1)}{\Gamma(\alpha+n+1)}},$$
$$n_{1R} = n_{1L}\sqrt{\alpha + n} \tag{3.6}$$

M is equal to $M = \frac{3}{2}$ and $\alpha = 2$.

For the -meson we have the profile function for the vector field $V_n(z)$ becomes [2,8,9]:

$$V_n(z) = k^2 z^2 \sqrt{\frac{2}{(1+n)}}\, L_n^1(k^2 z^2)\,. \tag{3.7}$$

In the soft-wall model the scalar field X has same profile function as in the hard-wall case.

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4. Boundary coupling constant from the bulk interaction lagranjian. As is known there are two kind of magnetic type interactions in vector-fermion fields interactions in the bulk if AdS space in holographic QCD.

1) First, L_{int} contains a term of minimal gauge interaction of the vector field with the current of fermions:

$$L^{(0)}_{\rho NN} = \overline{N_1} e^M_A \Gamma^A V_M N_1 + \overline{N_2} e^M_A \Gamma^A V_M N_2 \,. \tag{4.1}$$

2) A magnetic gauge coupling term $L^{(1)}$, which is known from ordinary QFT:

$$\mathcal{L}^{(1)}_{FNN} = i\frac{k_1}{2}(\bar{\Psi}_1 \Gamma^{MN}(F_L)_{MN}\,\Psi_1 + \bar{\Psi}_2 \Gamma^{MN}(F_R)_{MN}\Psi_2). \tag{4.2}$$

Where the $F_{MN} = \partial_M A_N - \partial_N A_M$ is stress tensor of the vector field A_M.

3) In [1] it was introduced one more interaction term $L^{(2)}$ for a fermion field with the scalar and vector or axial vector fields, which changes fermion's chirality in the bulk and consequently contributes to the chiral symmetry breaking on the boundary:

$$L^{(2)} = \frac{i}{2}k_2(\bar{\Psi}_1 X\, \Gamma^{MN}(F_R)_{MN}\Psi_2 - \bar{\Psi}_2 X^+ \Gamma^{MN}(F_L)_{MN}\Psi_1). \tag{4.3}$$

Here $\Gamma_{MN} = 1/2i\,[\Gamma_M \Gamma_N]$ are the Lorentz generators. F_{MN} in (4.1) and (4.2) contains two kind of terms, which are $\Gamma^{5v}F_{5v}$ and $\Gamma^{\mu v}F_{\mu v}$. It is useful to present the contributions made by these terms separately.

AdS/CFT correspondence suggests equality of partion functions:

$$Z_{CFT} = Z_{AdS}$$

The left-hand side is the partition function of a gauge theory with scale invariance (conformal invariance). The right-hand is the partition function of string theory on the AdS_5 space-time. Such a relation is known as the GKP-Witten relation. The vector current of nucleons can be calculated from the generating function Z which is defined as an exponent of classical bulk action S:

$$Z_{AdS} = e^{iS_{int}} \tag{4.4}$$

Here the interaction action S_{int} is the 5-dimensional integral of the interaction lagranjian terms (4.1), (4.2) and (4.3):

$$L_{int} = L^{(0)} + L^{(1)} + L^{(2)} \tag{4.5}$$

For the soft-wall model S_{int} is defined as following:

$$S_{int} = \int_0^\infty d^5x\sqrt{G}e^{-k^2z^2}\mathcal{L}_{int} \tag{4.6}$$

While in the hard-wall case we have no extra factor $e^{-k^2z^2}$ and integration carries out in the slice $0 < z \le z_m$ of AdS space-time. The metric of AdS space –time chosen in Poincare coordinates

$$ds^2 = \frac{1}{z^2}\left(-dz^2 + \eta_{\mu v}dx^\mu dx^v\right). \tag{4.7}$$

Z_{AdS} is holographically identified with the generating function Z_{QCD} of the boundary QCD:

$$Z_{AdS} = Z_{QCD}. \tag{4.8}$$

and the vacuum expectation value of the nucleon vector current in the boundary QCD theory will be found applying this equality as below:

$$< J_\mu > = -i\frac{\delta Z_{QCD}}{\delta A^0_\mu}|_{A^0_\mu=0} \tag{4.9}$$

Here, $A^0_\mu = A_\mu(q, z=0) = A_\mu(q)$ is the UV boundary value of the vector field $(A(q, z=0) = 1)$. The formula (4.9) will produce the vector current $J_\mu(p', p) = G_A \bar{u}(p')\gamma_\mu \frac{\tau^a}{2} u(p)$ and the vector form factor of nucleons G_A will be obtained as the integrals over the z direction of the bulk space-time. The A^0_μ is the source for the J_μ current. p and p' on the AdS gravity side are four momenta of

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the bulk spinor fields after and before the interaction with the vector field, respectively. But in the QCD side these are four momenta of final and initial nucleon, respectively.
Sum of these lagranjian terms define contributions of the interactions (4.2) and (4.3) into the coupling constants $g_{\rho NN}^{(1)nm}$ and f_{ρ}^{nm} which in the hard-wall model case have following expressions [1]:

$$g_{\rho NN}^{(1)nm} = 2\int_0^{\infty} \frac{dz}{z^3} V_0(z)[k_1\left(f_{1L}^{(n)*}(z) f_{1L}^{(m)}(z) - f_{2L}^{(n)*}(z) f_{2L}^{(m)}(z)\right) + k_2\, v(z)\left(f_{1L}^{(n)*}(z) f_{2L}^{(m)}(z) + f_{2L}^{(n)*}(z) f_{1L}^{(m)}(z)\right)].$$

$$f_{\rho}^{nm} = 4m_N\int_0^{\infty} \frac{dz}{z^3} V_0(z)[k_1\left(f_{1L}^{(n)*}(z) f_{1R}^{(m)}(z) - f_{2L}^{(n)*}(z) f_{2R}^{(m)}(z)\right) + k_2\, v(z)\left(f_{1L}^{(n)*}(z) f_{2R}^{(m)}(z) + f_{2L}^{(n)*}(z) f_{1R}^{(m)}(z)\right)]. \quad (4.10)$$

The $g_{\rho NN}^{(1)nm}$ constant corresponds to vector coupling and the f_{ρ}^{nm} constant does to tensor coupling in the vector-meson-nucleon interaction. In the case of soft-wall model the expressions for the $g_{\rho NN}^{(1)nm}$ and f_{ρ}^{nm} constants will have integration over the fifth z coordinate ranges $0 < z < \infty$ and these expressions contain extra $e^{-k^2 z^2}$ factor.

5. Numerical analysis. We calculate (4.10) integrals by use of MATEMATICA package**.** $k_1$and k_2 constants were found from fitting $g_{\rho NN}$ and $g_{\pi NN}$ coupling constants with their experimental values in the ground state of nucleons.

M_N	$g_1^{h.w}$	$g_2^{h.w}$	$g_{sum}^{h.w}$	$g_1^{s.w}$	$g_2^{s.w}$	$g_{sum}^{s.w}$
0.94	0.06	0.05	0.10	-0.37	85.84	85.80
1.44	0.09	-0.04	0.05	0.03	-113.04	-113.01

Table1: Numerical results for $g_{\rho NN}^{(1)nm}$

	$f_1^{h.w}$	$f_2^{h.w}$	$f_{sum}^{h.w}$	$f_1^{s.w}$	$f_2^{s.w}$	$f_{sum}^{s.w}$
0.94	0.21	0.05	0.03	-7.96	-15.11	-23.07
1.44	0.25	-0.01	0.25	-16.96	24.71	7.75

Table2: Numerical results for f_{ρ}^{nm}

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