Holographic Bottom-Up approach to hadron properties in nuclear medium

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Outline

Introduction

Applicability to QCD of Gauge / Gravity ideas. [1]

- N=4 SYM is different to QCD, but we can argue that in some situations both are closer. Ej: Heavy Ion Collisions.
- Gauge / Gravity ideas can be expanded in several directions. This gives us a possibility to get a field theory similar to QCD with gravity dual.
- You can use Gauge / Gravity as a nice frame to built phenomenological models with extra dimensions that reproduce some QCD facts (AdS/QCD models).
- AdS / QCD has been used in a successful way to study hadron physics at zero temperature and density, and also at finite temperature and in a dense medium.

[1] e.g., see J. Erdmenger, N. Evans, I. Kirsch and E. Threlfall, Eur. Phys. J. A **35**, 81 (2008).

Extensions of AdS / CFT to QCD, are related at two approaches:

- Top-Down approach.
  You start from a string theory on $AdS_{d+1} x C$, and try to get at low energies a theory similar to QCD in the border.
- Bottom-Up approach.
  Starting from QCD in 4d we try to build a theory with higher dimensions (not necessarily a string theory).

AdS / QCD models belong to the bottom-up approach, and here with Asymptotically AdS metrics with a non-dynamical dilaton, it is possible to reproduce some of the hadronic phenomenology.

Nucleon properties in vacuum using an AdS/QCD model [2]

[2] T. Gutsche, V. E. Lyubovitskij, I. Schmidt and A. V, Phys. Rev. D **86**, 036007 (2012).

⋆ Electromagnetic Form Factors.

Nucleon electromagnetic form factors F_1^N and F_2^N ($N = p, n$ correspond to proton and neutron) are conventionally defined by the matrix element of the electromagnetic current as

$$\langle p'|J^\mu(0)|p\rangle = \bar{u}(p')[\gamma^\mu F_1^N(Q^2) + \frac{i\sigma^{\mu\nu}}{2m_N} q_\nu F_2^N(Q^2)]u(p),$$

where $q = p' - p$ is the momentum transfer; m_N is the nucleon mass; F_1^N and F_2^N are the Dirac and Pauli form factors, which are normalized to electric charge e_N and anomalous magnetic moment k_N of the corresponding nucleon: $F_1^N(0) = e_N$ and $F_2^N(0) = k_N$.

In AdS / QCD models we consider

$$S = \int d^{d+1}x \sqrt{g} e^{-\Phi(z)} \left(\mathcal{L}_\Psi + \mathcal{L}_V + \mathcal{L}_{Int} \right),$$

where

$$ds^2 = \frac{1}{z^2} (\eta_{\mu\nu} dx^\mu dx^\nu - dz^2),$$

⋆ Hard Wall case: $\Phi(z) = Cte$ and z between 0 and z_0.

⋆ Soft Wall case: $\Phi(z) = \kappa^2 z^2$ and z between 0 and ∞.

Modes duals to nucleons satisfy the following equation of motion:

$$\left[i e_A^N \Gamma^A D_N - \frac{i}{2}(\partial_N \Phi) e_A^N \Gamma^A - (m_5 + \Phi(z)) \right] \Psi = 0,$$

where

$$D_N = \partial_N + \frac{1}{8}\omega_{NAB}[\Gamma^A, \Gamma^B] - iV_N,$$

and ω_{NAB} and Γ^A elements are related with metric used.

$$\Psi(x,z) = \Psi^L(x,z) + \Psi^R(x,z)$$

$$\Psi^{L/R}(x,z) = \psi^{L/R}(x)\ e^{-2A(z)}\ f^{L/R}(x,z)$$

In Soft Wall case

$$f_L(z) = N_L\ (\kappa z)^{5/2} e^{-\kappa^2 z^2/2} \quad and \quad f_R(z) = N_R\ (\kappa z)^{3/2} e^{-\kappa^2 z^2/2}$$

$$M_n^2 = 4\kappa^2(n+2)$$

For another side, according to the AdS/CFT dictionary, the $V_\mu(p)$ is the source for the 4D current operator J_μ^V.

$$\left[\partial_z\left(\frac{e^{-\Phi}}{z}\partial_z\right)+\frac{e^{-\Phi}}{z}p^2\right]V(p,z)=0,$$

$$V(Q,z)=\Gamma\left(1+\frac{Q^2}{4\kappa 2}\right)U\left(\frac{Q^2}{4\kappa 2},0;\kappa^2 z^2\right),$$

⋆ Proton Form Factors in AdS / QCD.

$$S = \int d^{d+1}x\sqrt{g}e^{-\Phi(z)}\mathcal{L}_{Int},$$

$$F_1^p(Q^2) = C_1(Q^2) + g_v C_2(Q^2) + \eta_V^p C_3(Q^2) \quad , \quad F_2^p(Q^2) = \eta_V^p C_4(Q^2),$$

where

$$C_1(Q^2) = \frac{1}{2}\int dz V(Q,z)(f_L^2(z) + f_R^2(z))$$

$$C_2(Q^2) = \frac{1}{2}\int dz V(Q,z)(f_L^2(z) - f_R^2(z))$$

$$C_3(Q^2) = \frac{1}{2}\int dz\ z\ \partial_z\ V(Q,z)(f_L^2(z) - f_R^2(z))$$

$$C_4(Q^2) = 2M\ \frac{1}{2}\int dz\ z\ V(Q,z)(f_L^2(z)\ f_R^2(z))$$

Nucleon properties in nuclear media with an alternative AdS/QCD model [3]

[3] A. V and M. A. M. Contreras, In progress.

⋆ Electromagnetic Form Factors in nuclear media. [4]

Assuming that nucleon is quasi-free in the nuclear medium, the electromagnetic current can be expressed as

$$\langle p'|J^{\mu}(0)|p\rangle = \bar{u}(p')[\gamma^{\mu} F_1^{N*}(Q^2) + \frac{i\sigma^{\mu\nu}}{2m_N^*} q_{\nu} F_2^{N*}(Q^2)]u(p),$$

where F_1^{N*} and F_2^{N*} are the Dirac and Pauli form factors in nuclear medium, which are normalized to electric charge e_N and anomalous magnetic moment k_N of the corresponding nucleon: $F_1^{N*}(0) = e_N$ and $F_2^{N*}(0) = k_N^*$.

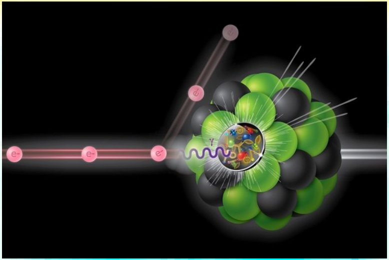
⋆ Scaling mass. [5]

$$\frac{M^*}{M} \sim 1 - 0.21 \frac{\rho_B}{\rho_0}$$

[4] G. Ramalho, K. Tsushima and A. W. Thomas, J. Phys. G **40**, 015102 (2013).

[5] K. Saito, K. Tsushima and A. W. Thomas, Prog. Part. Nucl. Phys. **58**, 1 (2007).

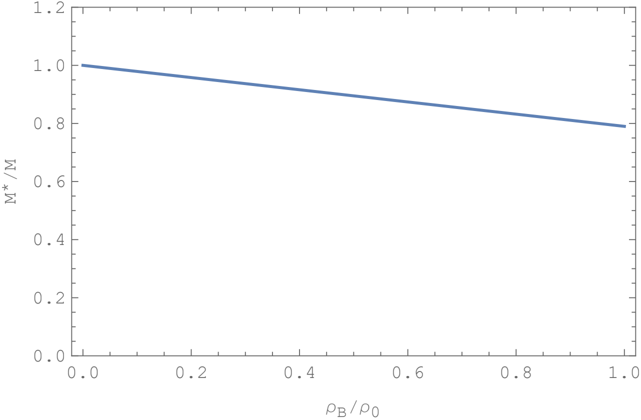
⋆ A different approach.



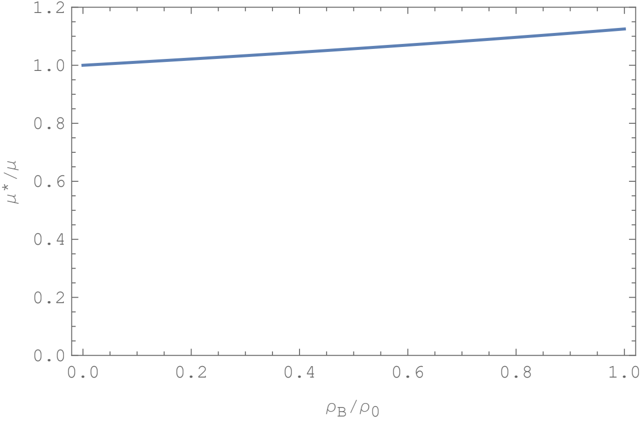
In AdS / QCD models media properties are coded in the background (usually in the metric), but dilaton although not dynamical, it is background also. So

$$\kappa \quad \rightarrow \quad \kappa_N = \sqrt{1 - 0.14\frac{\rho_B}{\rho_0}}\kappa, \qquad \textit{for modes dual to Proton.}$$

Nucleon properties in nuclear media with an alternative AdS/QCD model



Nucleon properties in nuclear media with an alternative AdS/QCD model



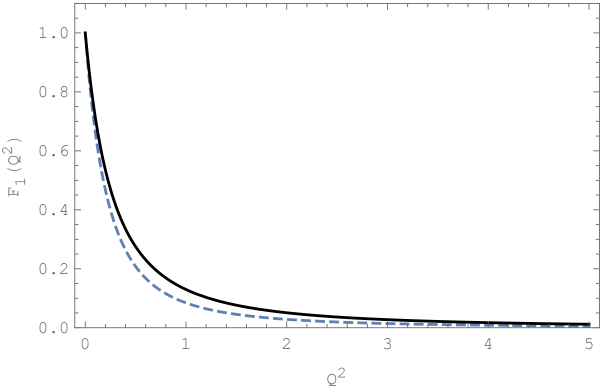


Figure: Dirac form factor for proton in media to $\rho_B/\rho_0 = 0$ (continous line) and $\rho_B/\rho_0 = 1$ (dashed line).

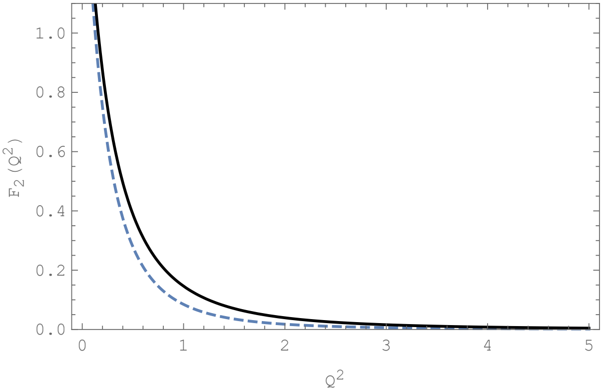


Figure: Pauli form factor for proton in media to $\rho_B/\rho_0 = 0$ (continous line) and $\rho_B/\rho_0 = 1$ (dashed line).

Final Comments and Conclusions

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- We show that dilaton field can capture part of the medium properties where hadrons are located.
- With a simple approach that considers hadron mass in the nuclear medium, it is possible to calculate electromagnetic form factors.
- In a qualitative sense, we got an agreement with properties of the nucleon in nuclei.
- We plan to use the idea to study other properties and other hadrons in nuclei.


That's all Folks!