# Revisiting Holographic Nuclear Matter in AdS/QCD

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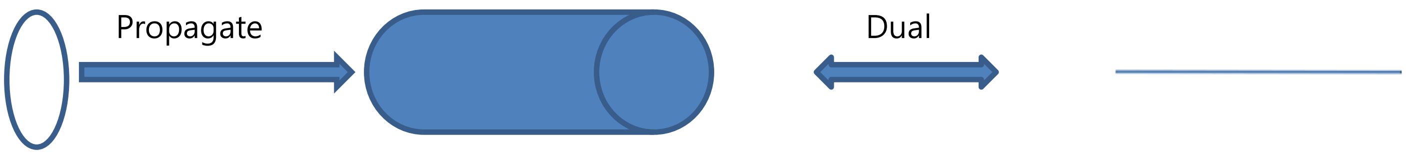
# 1. Intoruction to AdS/QCD Model For Baryons

# AdS/CFT Correspondence

Closed String : Gravity
Open String : Gauge Theory




AdS Gravity N=4 SYM Theory

| **4D generating functional** | ↔ | **5D classical effective action** |
|---|---|---|
| Operator | ↔ | 5D bulk field |
| [Operator] | ↔ | 5D mass |
| Current conservation | ↔ | Gauge symmetry |
| Resonances | ↔ | Klauza-Klein states |

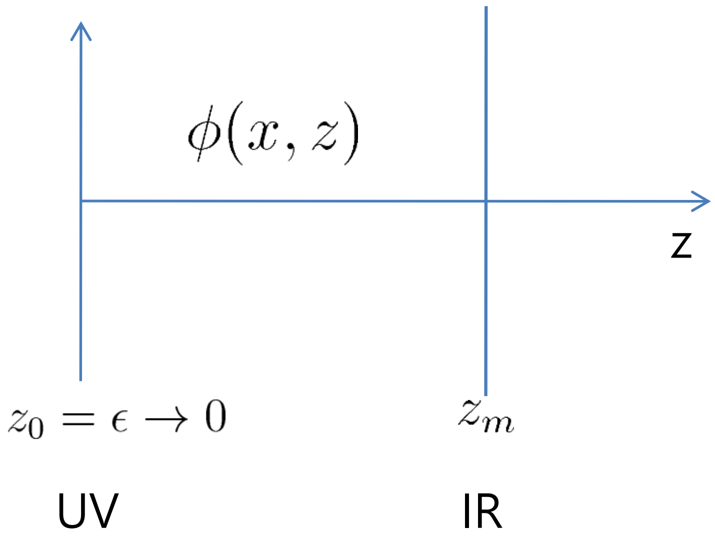
# AdS/CFT Dictionary

**AdS/CFT Dictionary**

| | | |
|---|---|---|
| Operator | $\Leftrightarrow$ | 5D bulk field |
| $\bar{\psi}\psi$ | $\Leftrightarrow$ | $\Phi(x,z)$ |
| $\bar{\psi}_L\gamma_\mu t^a\psi_L$ | $\Leftrightarrow$ | $L_\mu(x,z)$ |
| $\bar{\psi}_R\gamma_\mu t^a\psi_R$ | $\Leftrightarrow$ | $R_\mu(x,z)$ |
| $\mu\bar{\psi}\gamma_0\psi$ | $\Leftrightarrow$ | $V_0(x,z)$ |

# Hard Wall Model

*AdS5 space is compactified such that* $z_0 \leq z \leq z_m$



# Nucleons in Finite Densities

The effective action for nucleons,

$$S_{kin} = \int dz \int d^4x \sqrt{G_5}\left[i\bar{N}_1 e_A^M \Gamma^A D_M N_1 + i\bar{N}_2 e_A^M \Gamma^A D_M N_2 - m_5 \bar{N}_1 N_1 + m_5 \bar{N}_2 N_2\right]$$

$$S_m = \int dz \int d^4x \sqrt{G_5}\left[-g\bar{N}_1 X N_2 - g\bar{N}_2 X^\dagger N_1\right]$$

<u>$def$</u>

$$\Gamma^M = \{\gamma^\mu, -i\gamma^5\}, \qquad e_M^A = \frac{1}{z}\eta_M^A$$

$$D_M = \partial_M + \frac{i}{4}\omega_M^{AB}\Gamma_{AB} - i\,(A_L^a)_M\, t^a$$

$$\omega_M^{5A} = -\omega_M^{A5} = \frac{1}{z}\delta_M^A, \qquad \Gamma^{AB} = \frac{1}{2i}\left[\Gamma^A, \Gamma^B\right]$$

$$m_5^2 = \left(\Delta - \frac{d}{2}\right)^2 = \left(\frac{5}{2}\right)^2, \qquad A_L^a = V^a + A^a \approx V_0^a = \mu_q + c_q z^2$$

The equation of motion is given by

$$\Rightarrow \quad (ie_A^M \Gamma^A D_M - m_5)N_1 - gXN_2 = 0$$

# Nucleons in Finite Densities

**5D dual field of 4D quark field and 4D chemical potential**

$$\bar{\psi}\psi \leftrightarrow X \quad \mu\bar{\psi}\gamma_\mu\psi \leftrightarrow V_\mu$$

The scalar field at boundary

$$X = \frac{1}{2}m_q z + \frac{1}{2}\sigma z^3$$

The time component of vector field

$$V_0 = \mu + cz^2$$

**The equation of motion for proton with finite baryon densities,**

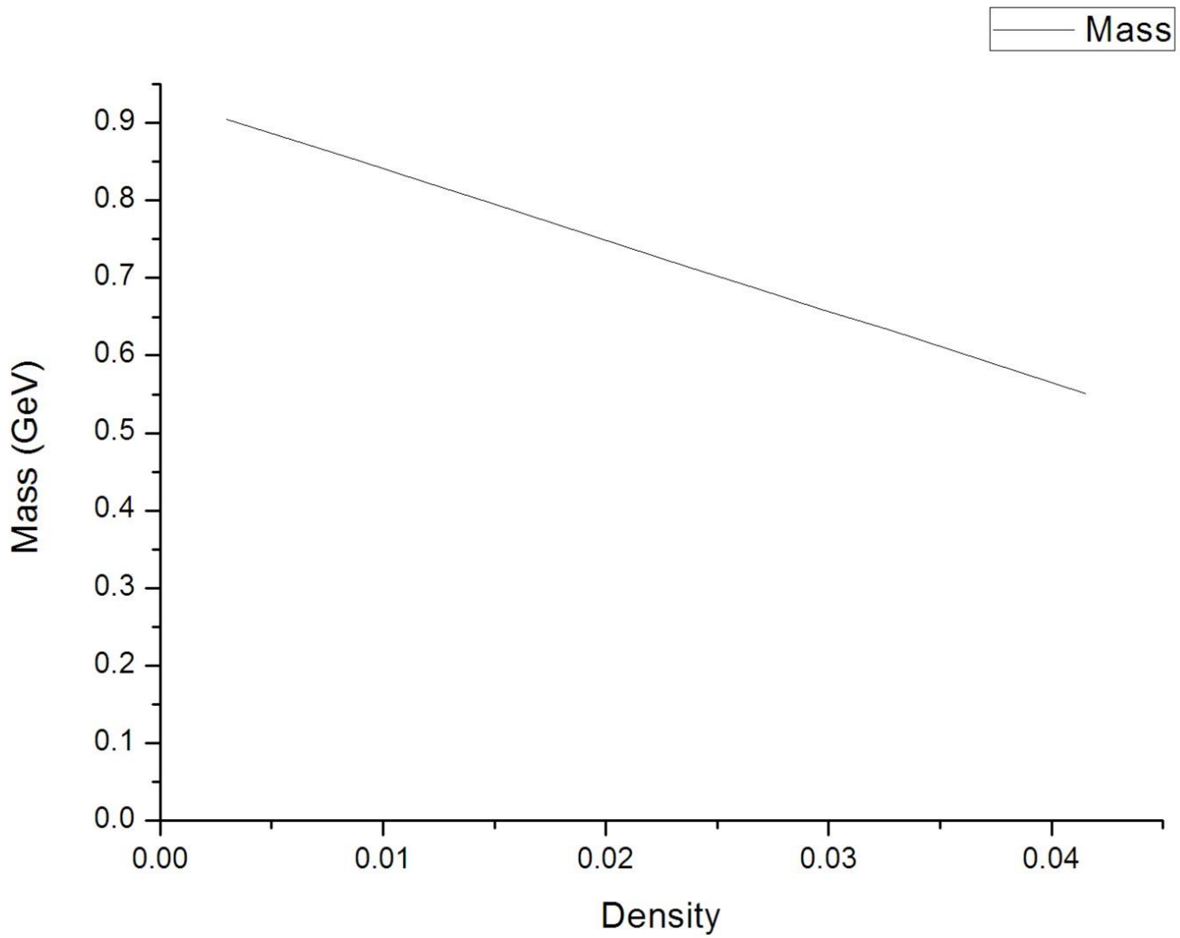
$$\{\partial_5^2 - \left[\frac{A'(z)}{A(z)} + \frac{4-m_5}{z}\right]\partial_5 + \left[\frac{2-m_5}{2} + \frac{2-m_5}{z}\frac{A'(z)}{A(z)} + \frac{(m_5+2)(2-m_5)}{z^2} + A(z)\left(m_p + V_0 + g\frac{X_{0p}}{z}\right)\right]\}p_{1R}(z) = 0$$

where,

$$A(z) = \left(m_p - \frac{1}{2}gm_u\right) + \left(c_q - \frac{1}{2}g\sigma_u\right)z^2$$

$$A'(z) = (2c_q - g\sigma_u)z$$

# Nucleon in Dense Medium



# 2. Nolen-Schiffer Anomaly

# Nolen-Schiffer Anomaly

The anomaly is the failure of theory to explain the mass differences between mirror nuclei or analog states.

$(Z_1 - Z_2 = 1)$

$$\delta = \Delta E_{expt} - \Delta E_{th}$$

increases with the mass number A and amounts to ~900 keV for A=208 .

**The mass difference between mirror nuclei**

$$\Delta M \equiv {}^{A}_{Z+1} M_N - {}^{A}_{Z} M_{N+1} = \Delta E_{EM} - \Delta m^*_{np}$$

- If one assume that effective neutron-proton difference is constant, this equation is not satisfied

- A possible resolution of the anomaly is the assumption that the effective mass diff. would decrease

# AdS/QCD Approach

The isospin structure of  model,

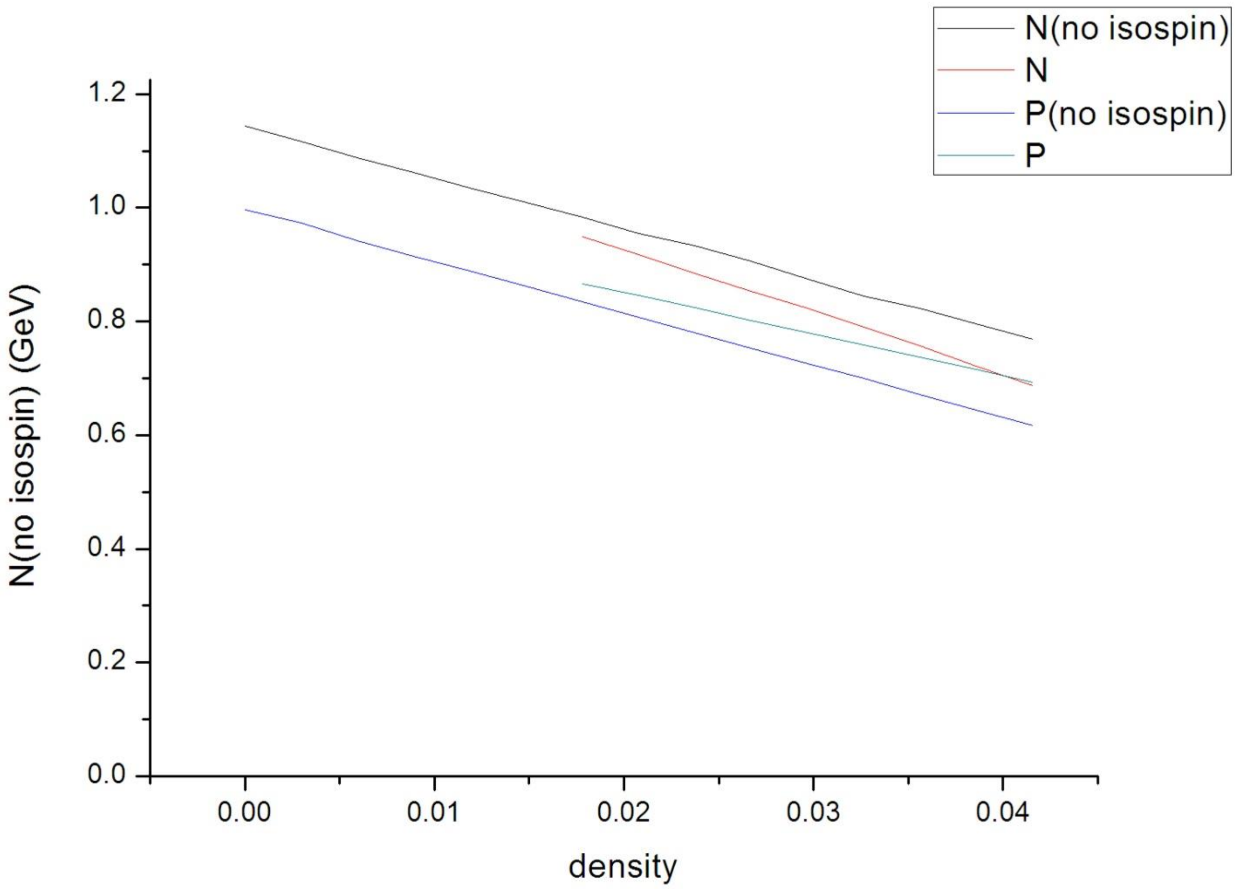
The quark mass difference

$$X = \frac{1}{2} m_q z + \frac{1}{2} \sigma z^3 \quad \Rightarrow \quad X = \frac{1}{2} \begin{pmatrix} m_u & 0 \\ 0 & m_d \end{pmatrix} z + \frac{1}{2} \begin{pmatrix} \sigma_u & 0 \\ 0 & \sigma_d \end{pmatrix} z^3$$

The isospin densities

$$V_0 = \mu_q + c_q z^2 \quad \Rightarrow \quad V_0 = (\mu_q + c_q z^2)\mathbb{I} + (\mu_I + c_I z^2) T^3$$

# NS anomaly


N(no isospin)
N
P(no isospin)
P
1.2
1.0
0.8
0.6
0.4
0.2
0.0
N(no isospin) (GeV)
0.00
0.01
0.02
0.03
0.04
density

# 3. Mass Decrease by Vacuum Energy Shift

# The Quark Condensate

The quark mass and condensate in AdS model.

$$X = \frac{1}{2} m_q z + \frac{1}{2} \sigma z^3$$

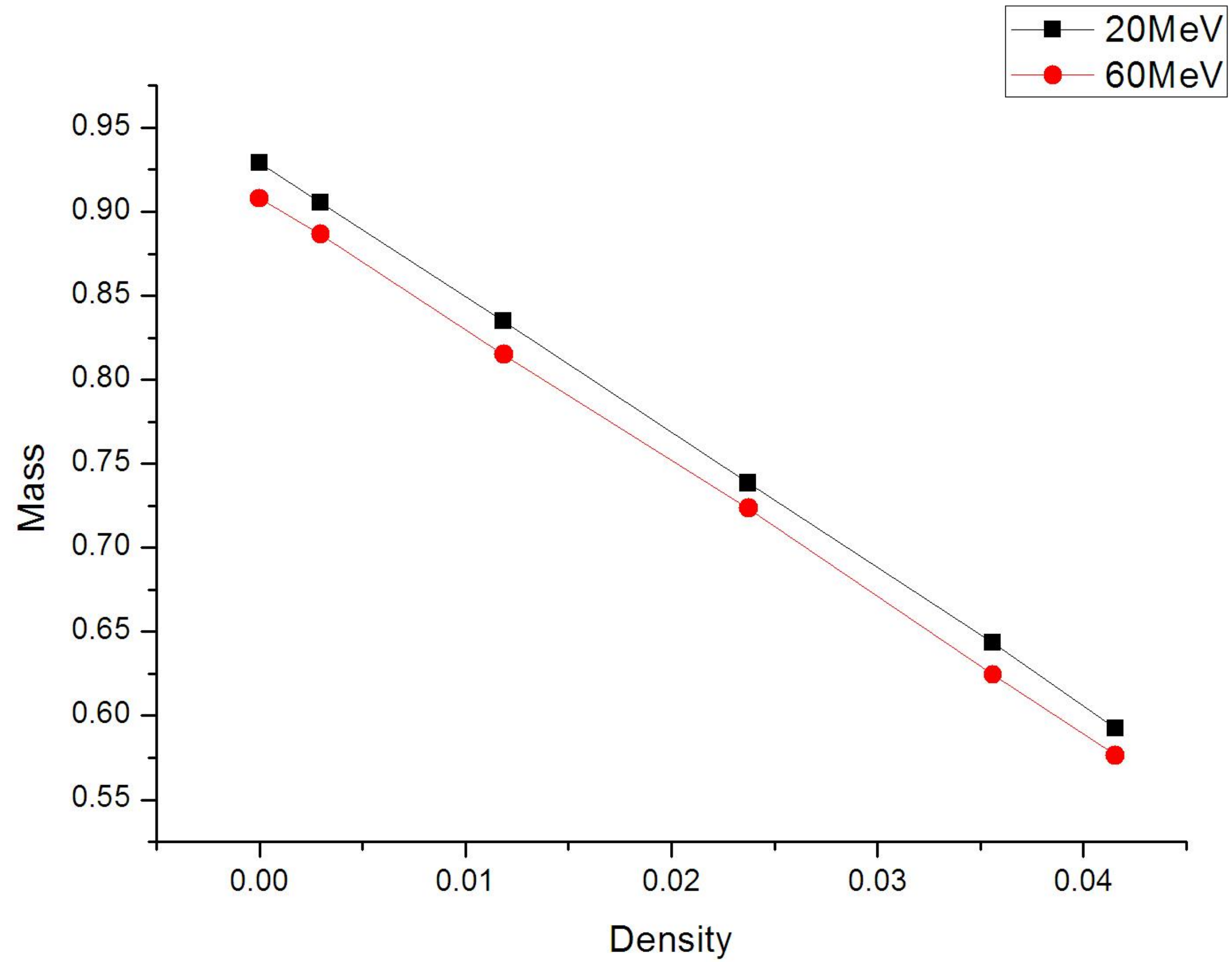
The quark condensate at low temperature

$$< \bar{q}q >_T = < 0|\bar{q}q|0 > (1 - \frac{T^2}{8 f_\pi^2})$$

The quark condensate at low density

$$< \bar{q}q >_\rho = < \bar{q}q >_0 (1 - 0.35 \frac{\rho}{\rho_0})$$

# Proton mass with Low T and Low Density



Thank you!

# Summary and Outlook

# 4. Walecka Model

# Walecka Model

$$\mathcal{L} = \overline{\psi}[\gamma_\mu(i\partial^\mu - g_\mathrm{v}V^\mu) - (M - g_\mathrm{s}\phi)]\psi + \frac{1}{2}(\partial_\mu\phi\partial^\mu\phi - m_\mathrm{s}^2\phi^2)$$
$$- \frac{1}{3!}\kappa\phi^3 - \frac{1}{4!}\lambda\phi^4 - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}m_\mathrm{v}^2V_\mu V^\mu + \delta\mathcal{L} \ ,$$

$$M^* = M - \frac{g_\mathrm{s}^2}{m_\mathrm{s}^2}\rho_\mathrm{s} + \frac{\kappa}{2g_\mathrm{s}m_\mathrm{s}^2}(M - M^*)^2 + \frac{\lambda}{6g_\mathrm{s}^2m_\mathrm{s}^2}(M - M^*)^3 \ ,$$