Present status of bottom up model: sample works

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Outline

1. Low energy QCD and hQCD
2. Examples

Low energy QCD and hQCD

- Mesons and baryons
- (spontaneous) Chiral symmetry breaking
- Condensates
- Various EFTs

Chiral symmetry at low energy

$$\mathcal{L} = i\bar{\psi}_j \partial\!\!\!/ \psi_j$$

Note that gluons are flavor-blind

$$\Lambda_V : \ \psi \longrightarrow e^{-i\frac{\vec{\tau}}{2}\vec{\Theta}}\psi \simeq (1 - i\frac{\vec{\tau}}{2}\vec{\Theta})\psi$$

: vector transform

$$\begin{aligned} i\bar{\psi}\partial\!\!\!/\psi &\longrightarrow i\bar{\psi}\partial\!\!\!/\psi - i\vec{\Theta}\left(\bar{\psi}i\partial\!\!\!/\frac{\vec{\tau}}{2}\psi - \bar{\psi}\frac{\vec{\tau}}{2}i\partial\!\!\!/\psi\right) \\ &= i\bar{\psi}\partial\!\!\!/\psi \end{aligned}$$

$$V^a_\mu = \bar{\psi}\gamma_\mu \frac{\tau^a}{2}\psi$$

$$\Lambda_A : \quad \psi \longrightarrow e^{-i\gamma_5\frac{\vec{\tau}}{2}\vec{\Theta}}\psi = (1 - i\gamma_5\frac{\vec{\tau}}{2}\vec{\Theta})\psi$$

: axial-vector transform

$$\begin{aligned} i\bar{\psi}\partial\!\!\!/\psi &\longrightarrow i\bar{\psi}\partial\!\!\!/\psi - i\vec{\Theta}\left(\bar{\psi}\, i\partial_\mu\gamma^\mu\gamma_5\frac{\vec{\tau}}{2}\psi + \bar{\psi}\,\gamma_5\frac{\vec{\tau}}{2}i\partial_\mu\gamma^\mu\,\psi\right) \\ &= i\bar{\psi}\partial\!\!\!/\psi \end{aligned}$$

$$A^a_\mu = \bar{\psi}\gamma_\mu\gamma_5\frac{\tau}{2}\psi$$

Chiral symmetry breaking

$$\delta \mathcal{L} = -m\left(\bar{\psi}\psi\right)$$

$$\Lambda_A : \; m\left(\bar{\psi}\psi\right) \longrightarrow m\bar{\psi}\psi - 2im\vec{\Theta}\left(\bar{\psi}\frac{\vec{\tau}}{2}\gamma_5\psi\right)$$

→ Explicit chiral symmtery breaking

$$\frac{m}{\Lambda_{\mathrm{QCD}}} \sim 0.05$$

→ chiral limit: m=0

$$< \bar{q}q >^{1/3} / \Lambda_{\mathrm{QCD}} \sim 1$$

→ SSB of chiral symmetry

$$m \sim (5-10)\ \mathrm{MeV},\ \ \Lambda_{\mathrm{QCD}} \sim 200\ \mathrm{MeV}, < \bar{q}q >^{1/3} \simeq -240\ \mathrm{MeV}$$

Mesons and chiral symmetry

pion-like state: $\vec{\pi} \equiv i\bar{\psi}\vec{\tau}\gamma_5\psi;$ sigma-like state: $\sigma \equiv \bar{\psi}\psi$

rho-like state: $\vec{\rho}_\mu \equiv \bar{\psi}\vec{\tau}\gamma_\mu\psi;$ a_1-like state: $\vec{a_1}_\mu \equiv \bar{\psi}\vec{\tau}\gamma_\mu\gamma_5\psi$

$$\begin{aligned}\pi_i: \quad i\bar{\psi}\tau_i\gamma_5\psi \quad &\longrightarrow \quad i\bar{\psi}\tau_i\gamma_5\psi + \Theta_j\left(\bar{\psi}\tau_i\gamma_5\gamma_5\frac{\tau_j}{2}\psi + \bar{\psi}\gamma_5\frac{\tau_j}{2}\tau_i\gamma_5\psi\right)\\ &= \quad i\bar{\psi}\tau_i\gamma_5\psi + \Theta_i\bar{\psi}\psi\end{aligned}$$

→ $\vec{\pi} \longrightarrow \vec{\pi} + \vec{\Theta}\sigma$

$\sigma \longrightarrow \sigma - \vec{\Theta}\vec{\pi}$ $\vec{\rho}_\mu \longrightarrow \vec{\rho}_\mu + \vec{\Theta} \times \vec{a_1}_\mu$

☆ 5D field contents

Operator ←→ 5D bulk field

$\bar{q}_R q_L$	$\longrightarrow$	scalar Φ
$\bar{q}_L \gamma^\mu q_L$	$\longrightarrow$	vector L_M
$\bar{q}_R \gamma^\mu q_R$	$\longrightarrow$	vector R_M

[Operator] ---- 5D mass

$$(\Delta - p)(\Delta + p - 4) = m_5^2 \qquad m_\phi^2 = -3$$

Linear sigma-model

$$\Lambda_V : \quad \pi^2 \longrightarrow \pi^2; \qquad \sigma^2 \longrightarrow \sigma^2 \qquad \Lambda_A : \quad \vec{\pi}^2 \longrightarrow \vec{\pi}^2 + 2\sigma\Theta_i\pi_i; \qquad \sigma^2 \longrightarrow \sigma^2 - 2\sigma\Theta_i\pi_i$$

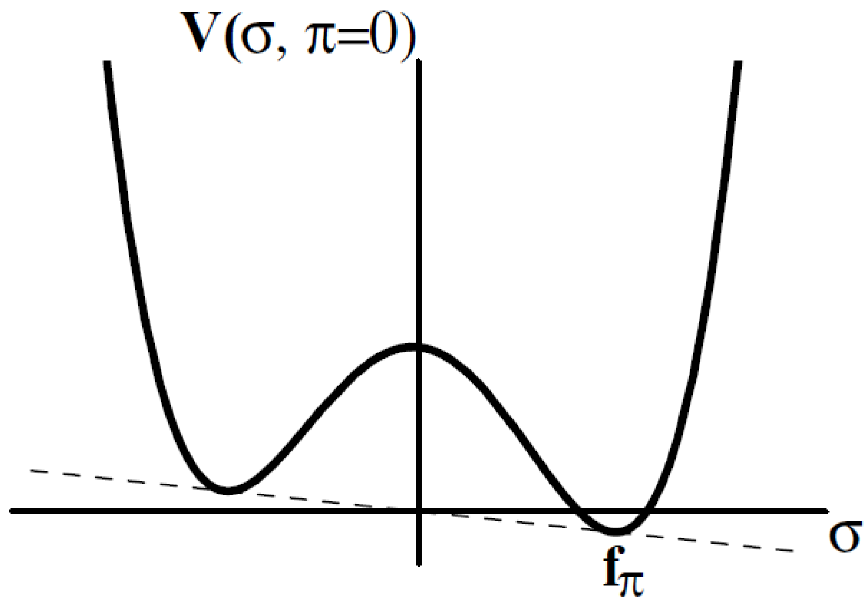
$$(\vec{\pi}^2 + \sigma^2) \xrightarrow{\Lambda_V, \Lambda_A} (\vec{\pi}^2 + \sigma^2)$$

* SSB →

$$V = V(\pi^2 + \sigma^2) = \frac{\lambda}{4}\left((\pi^2 + \sigma^2) - f_\pi^2\right)^2$$

$$\mathcal{L}_{L.S.} = \frac{1}{2}\partial_\mu\pi\partial^\mu\pi + \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma \; - \frac{\lambda}{4}\left((\pi^2 + \sigma^2) - f_\pi^2\right)^2$$

$$V(\sigma, \pi) = \frac{\lambda}{4}\left((\pi^2 + \sigma^2) - v_0^2\right)^2 - \epsilon\sigma$$



Potential of linear sigma-model with explicit symmetry breaking

$$v_0 = f_\pi - \frac{\epsilon}{2\lambda f_\pi^2}$$

chiral symmetry breaking in hQCD

Klebanov and Witten, 1999

$$\phi(x,z) \to z^{d-\Delta}\phi_0(x) + z^{\Delta}A(x) + \dots, z \to \epsilon\,,$$

where $\phi_0(x)$ is the source term of 4D operator $\mathcal{O}(x)$, and

$$A(x) = \frac{1}{2\Delta - d}\langle \mathcal{O}(x)\rangle\,.$$

For example, $\mathcal{O} = \bar{q}q$, $\phi(x,z) = v(z)$:

$$v(z) = c_1 z + c_2 z^3$$

$$c_1 \sim m_q, \quad c_2 \sim \langle \bar{q}q\rangle\,.$$

How about the vector meson?

* Gauged linear sigma model (with sigma) or Massive YM (without sigma) :

$$\mathcal{L}_{\rm MassiveYM} = {\rm Tr}\left[-\frac{1}{4}L_{\mu\nu}L^{\mu\nu} - \frac{1}{4}R_{\mu\nu}R^{\mu\nu} + \frac{1}{2}D_\mu\Phi D^\mu\Phi - \frac{1}{2}M_\Phi^2\Phi^\dagger\Phi\right] + \frac{1}{2}m_0^2\,{\rm Tr}(L_\mu L^\mu + R_\mu R^\mu)$$

* HLS, etc

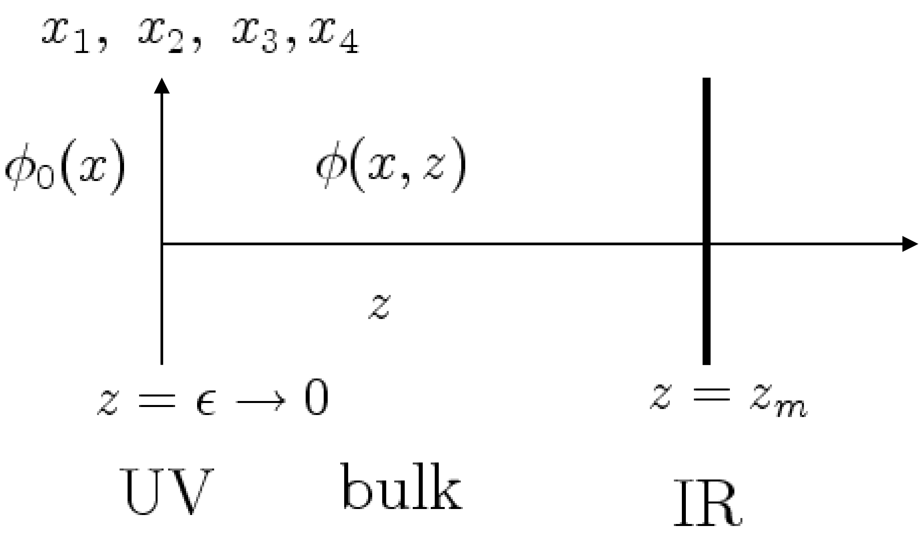
Hard–wall model

$$S_{\mathrm{hQCD-I}} = \int d^4x dz \sqrt{g} \mathcal{L}_5 \,,$$

$$\mathcal{L}_5 = \mathrm{Tr}\Big[-\frac{1}{g_5^2}(L_{MN}L^{MN} + R_{MN}R^{MN}) - |D_M\Phi|^2 - M_\Phi^2 |\Phi|^2 \Big] \,,$$

J. Erlich, E. Katz, D. T. Son and M. A. Stephanov, Phys. Rev. Lett. **95**, 261602 (2005)

L. Da Rold and A. Pomarol, Nucl.Phys. **B721**, 79 (2005)



Soft–wall model

$$S_{\mathrm{hQCD-II}} = \int d^4x dz e^{-\Phi} \mathcal{L}_5 \,, \quad \Phi = cz^2.$$

A. Karch, E. Katz, D. T. Son and M. A. Stephanov, Phys.Rev.D74:015005,2006

- Mode equation

$$\partial_z \left(e^{-B} \partial_z v_n \right) + m_n^2 e^{-B} v_n = 0,$$

where $B = \Phi(z) - A(z)$, with $e^{A(z)} = z^{-1}$. Substitute $v_n = e^{B/2}\psi_n$

$$-\psi_n'' + V(z)\psi_n = m_n^2 \psi_n, \qquad V(z) = \frac{1}{4}(B')^2 - \frac{1}{2}B''.$$

- With $\Phi = z^2$: $V = z^2 + \frac{3}{4z^2}$ — 2d harmonic oscillator (radial, $m = 1$).

$$m_n^2 = 4(n+1)$$

$$\text{QCD}: \ \mu_q \psi^\dagger \psi \ (= \mu_q \bar{\psi}\gamma_0\psi) \leftrightarrow \text{Gravity}: \ V_0(x,z) = \mu_q + \cdots, \ z \to 0 \,.$$

The low-energy dynamics is governed by the familiar chiral Lagrangian for the pion field $\Sigma \in SU(2)$: $\mathcal{L} = \frac{1}{4} f_\pi^2 \mathrm{Tr}[\partial_\mu \Sigma \partial_\mu \Sigma^\dagger - 2m_\pi^2 \mathrm{Re}\Sigma]$, which contains the pion decay constant f_π and vacuum pion mass m_π as phenomenological parameters. The isospin chemical potential further breaks $SU(2)_{L+R}$ down to $U(1)_{L+R}$. Its effect can be included to leading order in μ_I without additional phenomenological parameters by promoting $SU(2)_L \times SU(2)_R$ to a local gauge symmetry and viewing μ_I as the zeroth component of a gauge potential [6]. Gauge invariance thus fixes the way μ_I enters the chiral Lagrangian:

$$\mathcal{L}_{\text{eff}} = \frac{f_\pi^2}{4} \mathrm{Tr} \nabla_\nu \Sigma \nabla_\nu \Sigma^\dagger - \frac{m_\pi^2 f_\pi^2}{2} \mathrm{Re}\mathrm{Tr}\Sigma \,,$$

where the covariant derivative is defined as

$$\nabla_0 \Sigma = \partial_0 \Sigma - \frac{\mu_I}{2} (\tau_3 \Sigma - \Sigma \tau_3) \,.$$

Dense AdS/QCD

$$\text{QCD}: \ \mu_q \psi^\dagger \psi \ (= \mu_q \bar{\psi}\gamma_0 \psi) \leftrightarrow \text{Gravity}: \ V_0(x,z) = \mu_q + \cdots, \ z \to 0\,.$$

$$\text{4D generating functional}: Z_4[\phi_0(x)] = \int \mathcal{D}[\Phi] \exp\{iS_4 + i\int \phi_0(x)\mathcal{O}\}\,,$$

$$\text{5D (classical) effective action}: \Gamma_5[\phi(x,z) = \phi_0(x)]\,; \phi_0(x) = \phi(x, z=0).$$

$$\text{AdS/CFT correspondence}: Z_4 = \Gamma_5.$$

EFI-07-08

Baryon Number-Induced Chern-Simons Couplings of Vector and Axial-Vector Mesons in Holographic QCD

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(Dated: April 2007)

We show that holographic models of QCD predict the presence of a Chern-Simons coupling between vector and axial-vector mesons at finite baryon density. In the AdS/CFT dictionary, the coefficient of this coupling is proportional to the baryon number density, and is fixed uniquely in the five-dimensional holographic dual by anomalies in the flavor currents. For the lightest mesons, the coupling mixes transverse ρ and a_1 polarization states. At sufficiently large baryon number densities, it produces an instability, which causes the ρ and a_1 mesons to condense in a state breaking both rotational and translational invariance.

Examples from bottom-ups

- Dense matter
- Heavy quarkonium
- Phase transition
- Nuclei, form factor, tensor meson, Skyrme model in hQCD, etc

The Lagrangian is thus

$$S = \int d^4x dz \sqrt{g} \mathrm{Tr}\left[|DX|^2 + 3|X|^2 - \frac{1}{4g_5^2}(F_L^2 + F_R^2) \right] + S_{\mathrm{CS}}.$$

The Chern-Simons term is given by

$$S_{\mathrm{CS}} = \frac{N_c}{24\pi^2} \int [\omega_5(A_L) - \omega_5(A_R)],$$

where $d\omega_5 = \mathrm{Tr}F^3$, N_c is the number of colors, and $A_{L,R} = \hat{A}_{L,R}\hat{t} + A^a_{L,R}t^a$ where t^a are the generators of $SU(N_f)_{L,R}$ normalized so that $\mathrm{Tr}t^a t^b = \delta^{ab}/2$ and $\hat{t} = \mathbf{1}/\sqrt{2N_f}$ is the generator of the $U(1)$ subalgebra of $U(N_f)$.

$$\rightarrow \quad \frac{N_c}{24\pi^2}\frac{3}{8} \int d^4x dz \, \epsilon^{MNPQ}(\hat{A}_0^L \mathrm{Tr}F^L_{MN}F^L_{PQ} - \hat{A}_0^R \mathrm{Tr}F^R_{MN}F^R_{PQ}),$$

$$S = \int d^4x \left[\frac{1}{2}\partial_\mu \pi^a \partial^\mu \pi^a - \frac{1}{2} m_\pi^2 \pi^a \pi^a - \frac{1}{4}(\rho_{\mu\nu}^a)^2 \right.$$
$$- \frac{1}{4}(a_{\mu\nu}^a)^2 + \frac{1}{2} m_\rho^2 \rho_\mu^a \rho^{a\mu} + \frac{1}{2} m_a^2 a_\mu^a a^{a\mu}$$
$$\left. + \mu \epsilon^{ijk} \left(\rho_i^a \partial_j a_k^a + a_i^a \partial_j \rho_k^a \right) \right]$$

Holographic nuclear matter in the AdS/QCD model

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We study the physics at finite nuclear density in the framework of the AdS/QCD model with a holographic baryon field included. Based on a mean field type approach, we introduce the nucleon density as a bi-fermion condensate of the lowest mode of the baryon field and calculate the density dependence of the chiral condensate and the nucleon mass. We observe that the chiral condensate as well as the mass of nucleon decrease with increasing nuclear density. The resulting density dependence is, however, much weaker than those obtained in earlier studies based on other QCD effective theories. We also consider the mass splitting of charged vector mesons in isospin asymmetric nuclear matter.

Mean field approach:

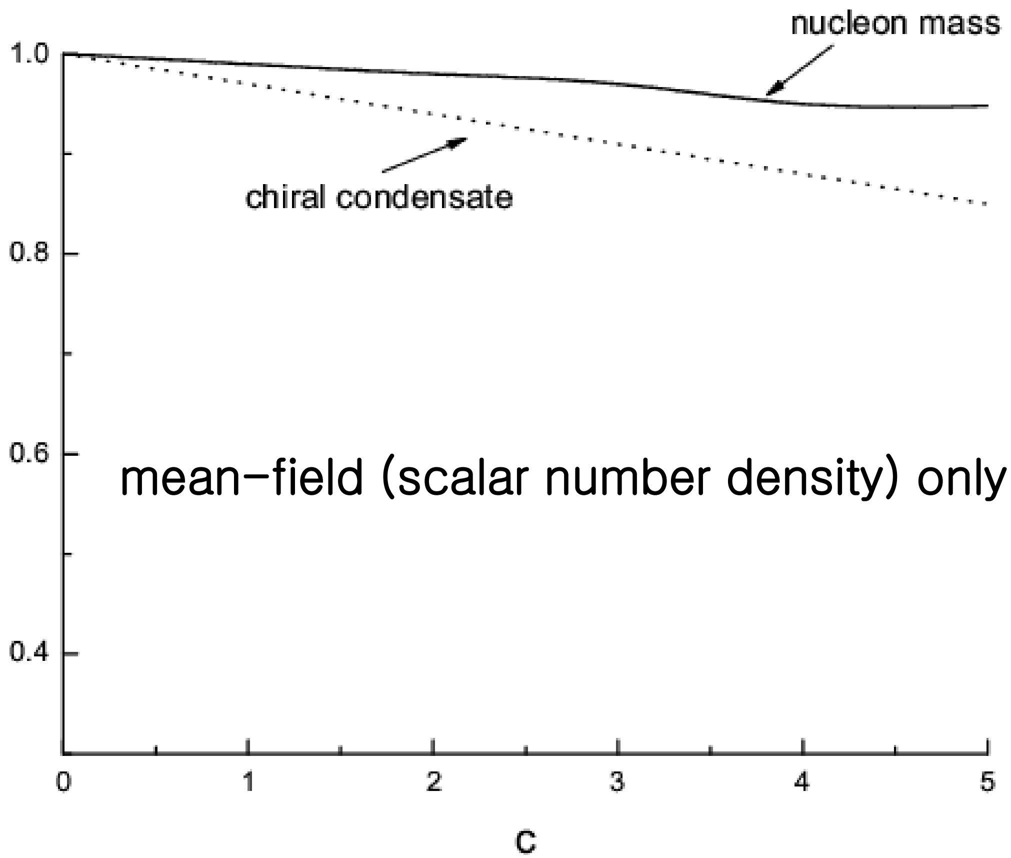
$$\langle \bar{N}(x,z)\gamma^0 N(x,z)\rangle = \sum f(z)^2 \langle \psi(x)^\dagger \psi(x)\rangle \,;\, \rho_B = \langle \psi(x)^\dagger \psi(x)\rangle$$

1. Chiral condensate $X_0 = \langle X \rangle$

$$[\partial_z^2 - \frac{3}{z}\partial_z + \frac{3}{z^2}]X_0 = \frac{1}{4}\frac{g}{z^2}(f_{2R}^2 - f_{1R}^2)\rho_s \quad \text{where } \rho_s \equiv \langle \bar{\psi}(x)\psi(x)\rangle .$$

$$X_0(z) = \frac{1}{2}m_q z + \frac{1}{2}\sigma z^3 \,,$$

2. In-medium nucleon mass (iteratively)



$$\rho_B = c\rho_0$$

What about mean-field approach + standard AdS/CFT (number density) ?
Note, however, that the scalar in nuclear matter is not chiral partner of the pion in mean field approach.

How to build a hQCD model with non-chiral scalar and U(1) vector?

Heavy quarkonium in a holographic QCD model

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Encouraged by recent developments in AdS/QCD models for the light quark system, we study heavy quarkonium in the framework of the AdS/QCD models. We calculate the masses of $c\bar{c}$ vector meson states using the AdS/QCD models at zero and at finite temperature. Among the models adopted in this work, we find that the soft-wall model describes the low-lying heavy quark meson states at zero temperature relatively well. At finite temperature, we observe that once the bound state is above T_c, its mass will increase with temperature until it dissociates at a temperature of around 494 MeV. It is shown that the dissociation temperature is fixed by the infrared cutoff of the models. The present model serves as a unified nonperturbative model to investigate the properties of bound quarkonium states above T_c.

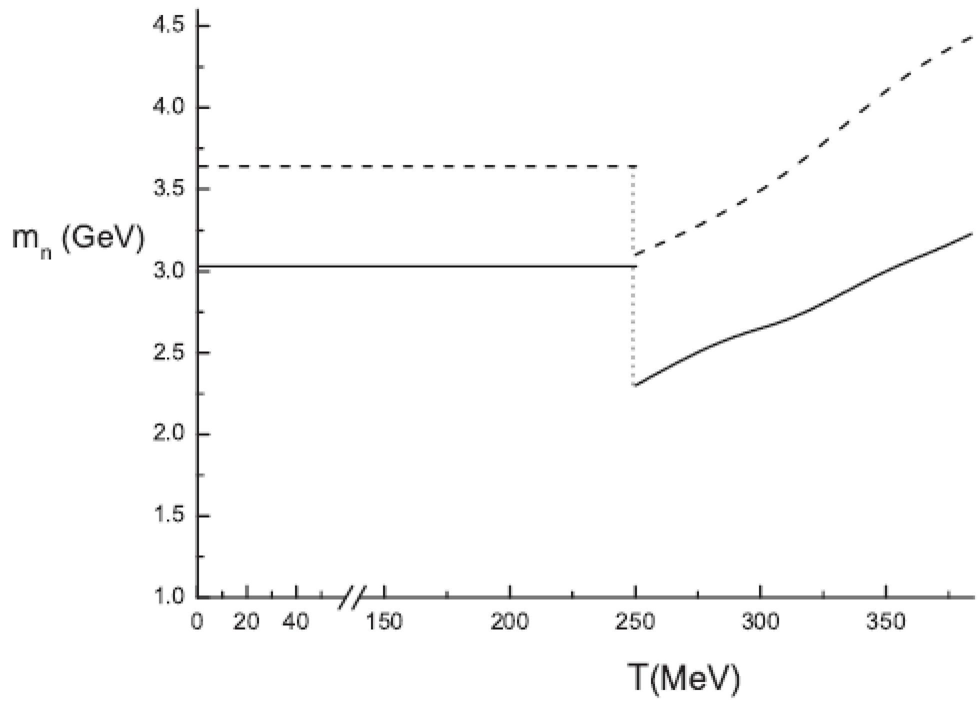

FIG. 1. The mass of the $c\bar{c}$ bound state in the vector channel at finite temperature, obtained in the soft-wall model. Here we show the first two modes, $n = 0, 1$.

$T_d^H = \sqrt{c}/\pi$, and so the predicted dissociation temperature in the soft-wall model is ~494 MeV.

Effect of the gluon condensate on the holographic heavy quark potential

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The gluon condensate is very sensitive to the QCD deconfinement transition since its value changes drastically with the deconfinement transition. We calculate the gluon condensate dependence of the heavy quark potential in AdS/CFT to study how the property of the heavy quarkonium is affected by a relic of the deconfinement transition. We observe that the heavy quark potential becomes deeper as the value of the gluon condensate decreases. We interpret this as a dropping of the heavy quarkonium mass just above the deconfinement transition. We finally argue that dropping of the gluon condensate and the pure thermal effect are competing with each other in the physics of heavy quarkonium at high temperature.

Towards the gravity dual of quarkonium in the strongly coupled QCD plasma

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We build a "bottom-up" holographic model of charmonium by matching the essential spectral data. We argue that these data must include not only the masses but also the decay constants of the J/ψ and ψ' mesons. Relative to the "soft-wall" models for *light* mesons, such a matching requires two new features in the holographic potential: an overall upward shift as well as a narrow "dip" near the holographic boundary. We calculate the spectral function as well as the position of the complex singularities (quasinormal frequencies) of the retarded correlator of the charm current at finite temperatures. We further extend this analysis by showing that the residue associated with such a singularity is given by the boundary derivative of the appropriately normalized quasinormal mode. We find that the "melting" of the J/ψ spectral peak occurs at a temperature $T \approx 540$ MeV, or $2.8T_c$, in good agreement with lattice results.

$$U_{(a,c)} = U_{(a)} + c^2 = 3/(4z^2) + (a^2 z)^2 + c^2.$$

	Experiment	$U_{(a)}$	$U_{(a,c)}$
Observable	(MeV)	(MeV)	(MeV)
$m_{J/\psi}$	3096	3096*	3096*
$m_{\psi'}$	3685	4378	3685*
$f_{J/\psi}$	416	348	145
$f_{\psi'}$	296	348	173

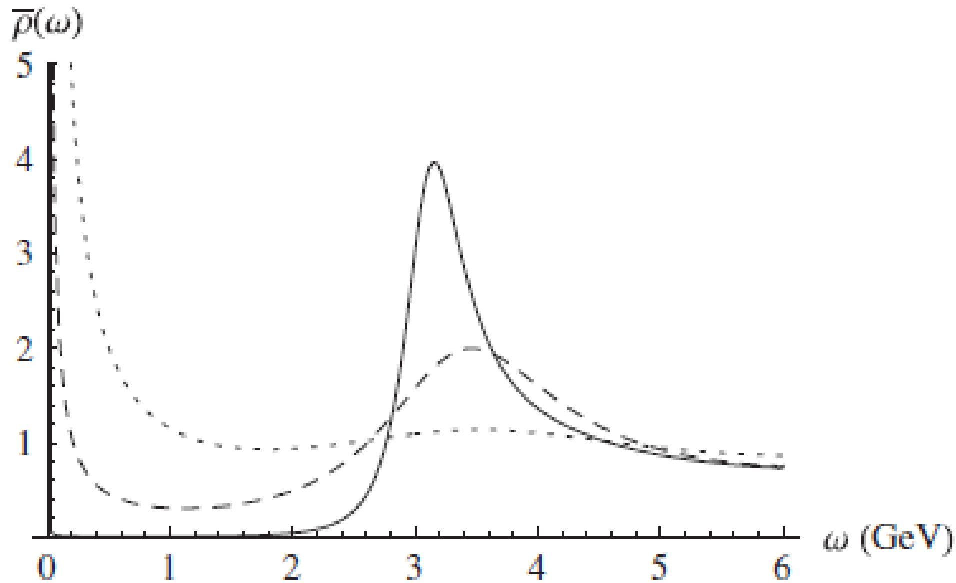

FIG. 3. Rescaled spectral function, Eq. (32), at $T = 200$ (solid curve), 400 (dashed curve), and 600 MeV (dotted curve) in the holographic model of this paper.

Finally, we find that the new features of the holographic potential, such as the dip, which we introduce to model quarkonium more realistically, strengthen the robustness of the J/ψ peak, allowing it to persist out to temperatures of about 540 MeV, i.e., $2.8T_c$, according to our criterion.

Heavy quarkonium states with the holographic potential

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Abstract: The quarkonium states in a quark-gluon plasma is examined with the heavy quark potential implied by the holographic principle. Both the vanila AdS-Schwarzschild metric and the one with an infrared cutoff are considered. The dissociation temperature is calculated by solving the Schrödinger equation of the potential model. In the case of the AdS-Schwarzschild metric with a IR cutoff, the ratios of the dissociation temperatures for J/ψ and Υ with the U-ansatz of the potential to the deconfinement temperature are found to agree with the lattice results within a factor of two.

ansatz	J/ψ(holographic)	J/ψ(lattice)	Υ(holographic)	Υ(lattice)
F	NA	1.1	1.3-2.1	2.3
U	1.2-1.7	2.0	2.5-4.2	4.5

Table 3: The ratio T_d/T_c for the 1S state from the holographic potential and that from the lattice QCD

Deconfinement phase transition in holographic QCD with matter

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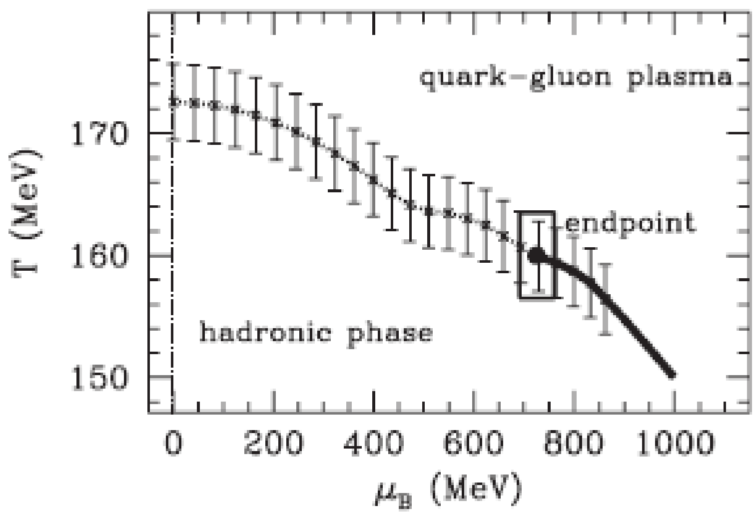
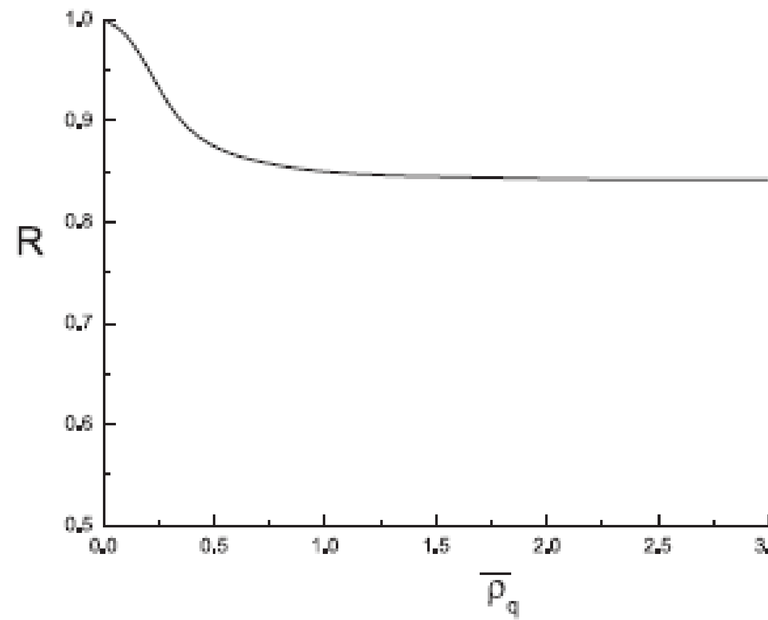
In the framework of a holographic QCD approach we study the influence of matter on the deconfinement temperature T_c. We first consider the quark flavor number (N_f) dependence of T_c. We observe that T_c decreases with N_f, which is consistent with a lattice QCD result. We also delve into how the quark number density ρ_q affects the value of T_c. We find that T_c drops with increasing ρ_q. In both cases, we confirm that the contributions from quarks are suppressed by $1/N_c$, as it should be, compared to the ones from a gravitational action (pure Yang-Mills theory).


quark–gluon plasma
endpoint
hadronic phase
T (MeV)
170
160
150
0
200
400
600
800
1000
μ_B (MeV)


R
1.0
0.9
0.8
0.7
0.6
0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
$\overline{\rho_q}$

Isospin and strangeness matter: K-I. Kim, Y. Kim, S. H. Lee

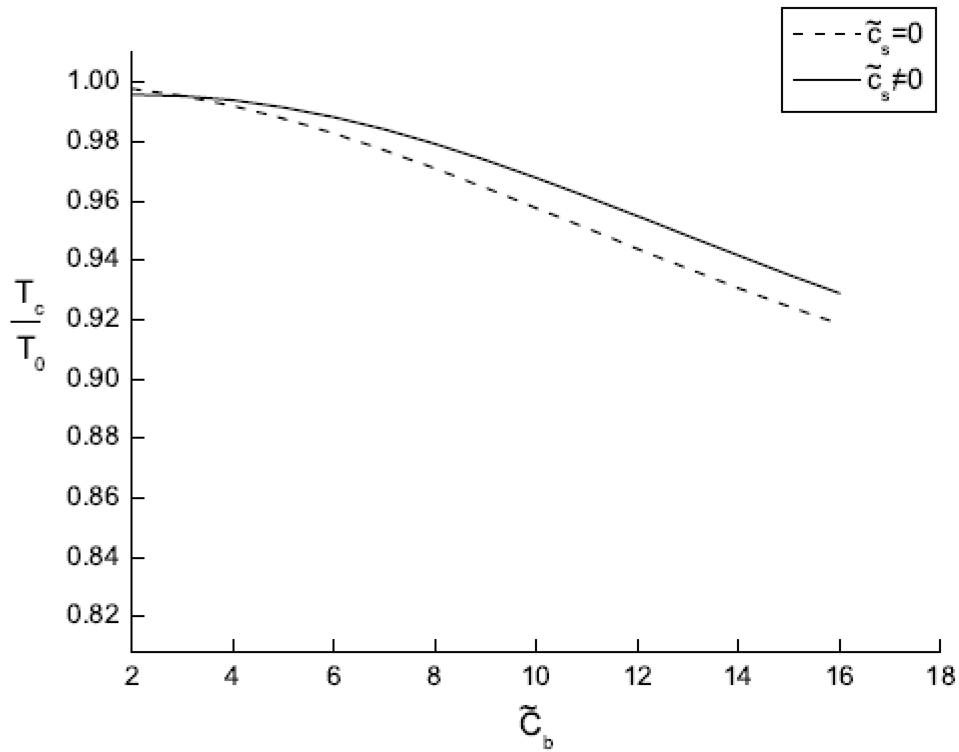


FIG. 2: The critical temperature at finite strange density. The solid line is for $\tilde{c}_s \neq 0$ while the dashed line is for $\tilde{c}_s = 0$, where $\tilde{c}_s = c_s z_m^3$ and $\tilde{c}_b = c_b z_m^3$.

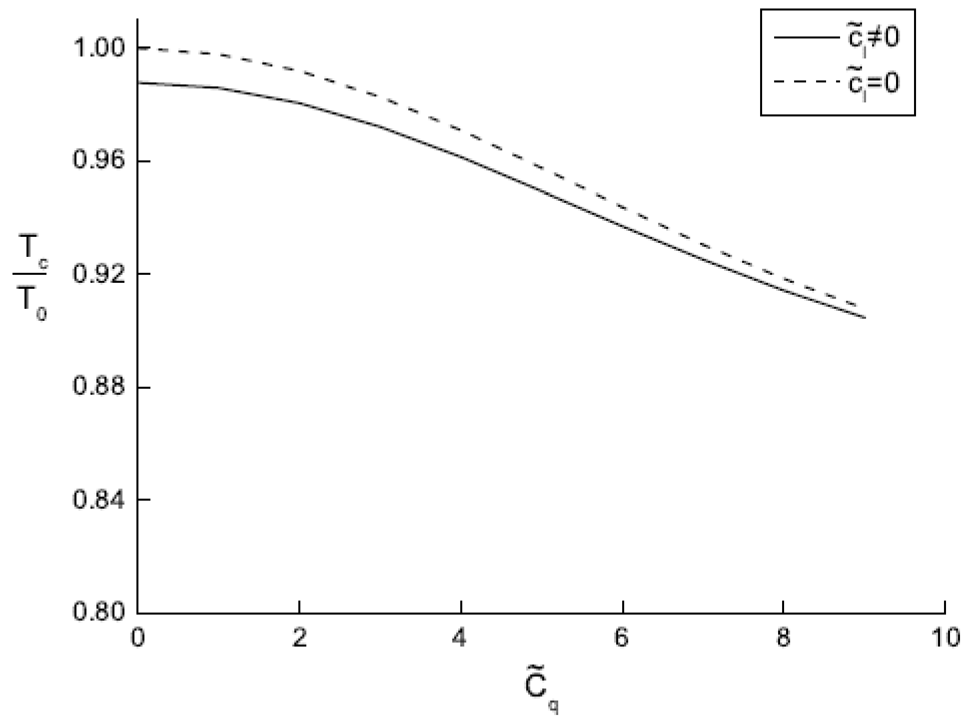


FIG. 4: The critical temperature at finite isospin. The dashed line is for $\tilde{c}_I = 0$ while the solid line is for $\tilde{c}_I \neq 0 \left(\tilde{c}_I = c_I z_m^3\right)$.

Quark number susceptibility with finite chemical potential in holographic QCD

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Abstract: We study the quark number susceptibility in holographic QCD with a finite chemical potential or under an external magnetic field at finite temperature. We first consider the quark number susceptibility with the chemical potential. We observe that approaching T_c from high temperature regime, χ_q/T^2 develops a peak as we increase the chemical potential, which confirms recent lattice QCD results. We discuss this behavior in connection with the existence of the critical end point in the QCD phase diagram. We also consider the quark number susceptibility under the external magnetic field. We predict that the quark number susceptibility exhibits a blow-up behavior at low temperature as we raise the value of the magnetic field. We finally spell out some limitations of our study.

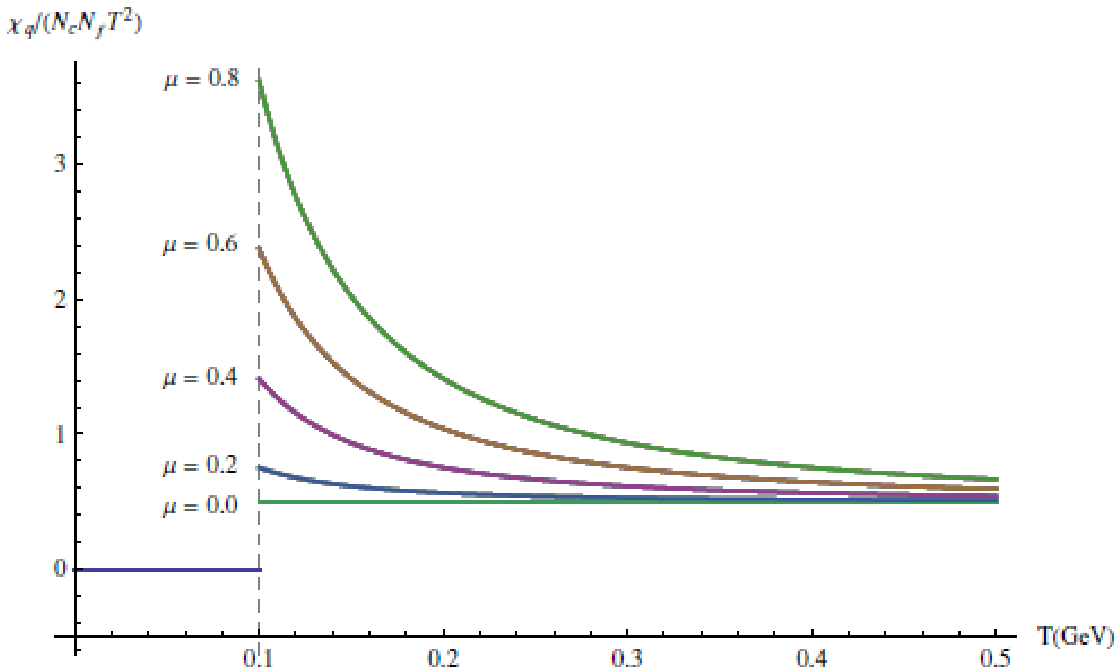
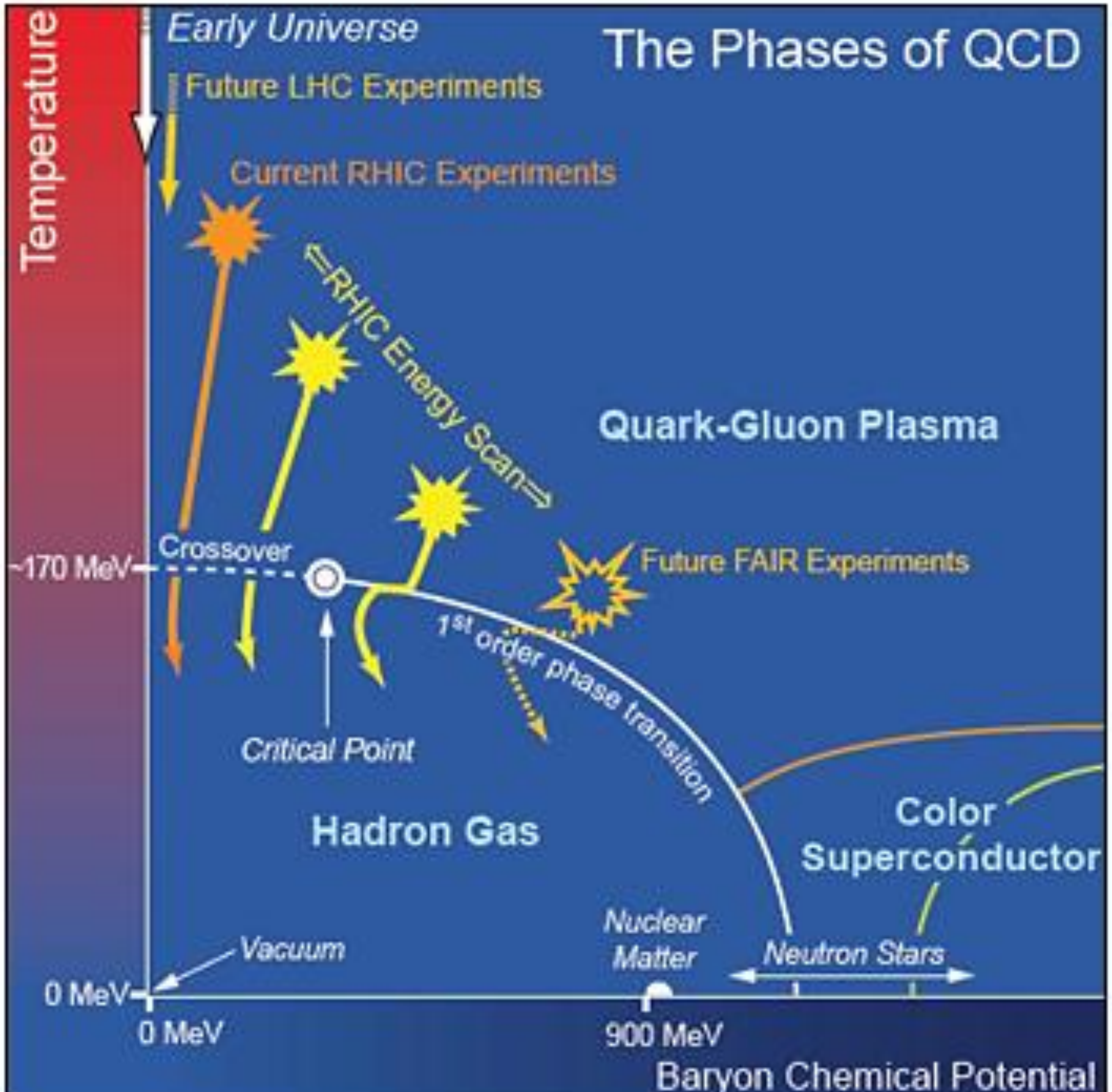


Figure 1. $\chi_q/(N_cN_fT^2)$ in the hard wall model for varying μ(GeV) with $N_c = 3$ and $N_f = 2$.


The Phases of QCD
Temperature
Early Universe
Future LHC Experiments
Current RHIC Experiments
⇐RHIC Energy Scan⇒
Quark-Gluon Plasma
Future FAIR Experiments
~170 MeV
Crossover
Critical Point
1st order phase transition
Hadron Gas
Color Superconductor
Nuclear Matter
Neutron Stars
Vacuum
0 MeV
0 MeV
900 MeV
Baryon Chemical Potential

Self-bound dense objects in holographic QCD

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Abstract: We study a self-bound dense object in the hard wall model. We consider a spherically symmetric dense object which is characterized by its radial density distribution and non-uniform but spherically symmetric chiral condensate. For this we analytically solve the partial differential equations in the hard wall model and read off the radial coordinate dependence of the density and chiral condensate according to the AdS/CFT correspondence. We then attempt to describe nucleon density profiles of a few nuclei within our framework and observe that the confinement scale changes from a free nucleon to a nucleus. We briefly discuss how to include the effect of higher dimensional operator into our study. We finally comment on possible extensions of our work.

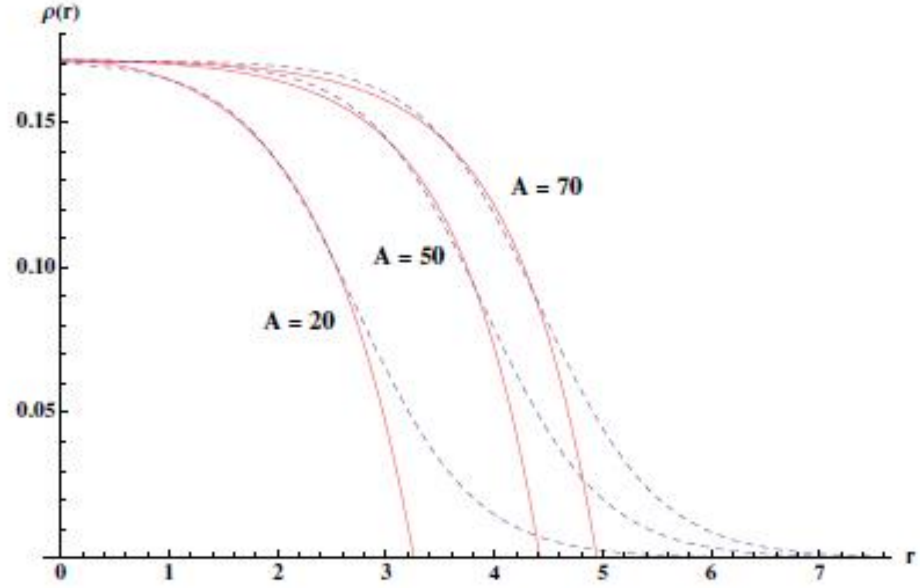

Figure 5. Nucleon density as a function of the distance to the center of the nucleus obtained from holographic QCD: $1/z_m \sim 72.8\,\mathrm{MeV}$ for $A = 20$, and $1/z_m \sim 79.0\,\mathrm{MeV}$ for $A = 50$, and $1/z_m \sim 78.5\,\mathrm{MeV}$ for $A = 70$.

THE PION FORM FACTOR IN AdS/QCD

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Holographic QCD provides a unique framework in which to compute QCD observables. In this talk we summarize recent numerical work on computing the pion electromagnetic form factor using an AdS/QCD action that includes both spontaneous and explicit chiral symmetry breaking. We consider both hard- and soft-wall model results and develop an intermediate background that supports the best features of both. We also begin to see possible evidence in the fit for the presence of $1/N_c$ corrections.

Baryon physics in holographic QCD

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Abstract

In a simple holographic model for QCD in which the Chern–Simons term is incorporated to take into account the QCD chiral anomaly, we show that baryons arise as stable solitons which are the 5D analogs of 4D skyrmions. Contrary to 4D skyrmions and previously considered holographic scenarios, these solitons have sizes larger than the inverse cut-off of the model, and therefore they are predictable within our effective field theory approach. We perform a numerical determination of several static properties of the nucleons and find a satisfactory agreement with data. We also calculate the amplitudes of "anomalous" processes induced by the Chern–Simons term in the meson sector, such as $\omega \to \pi\gamma$ and $\omega \to 3\pi$. A combined fit to baryonic and mesonic observables leads to an agreement with experiments within 16%.

Table 1

Predictions for the baryon static quantities where M_5, L and α have been determined from the experimental values of $F_\pi = 87$ MeV, $m_\rho = 775$ MeV and $F_\omega / F_\rho = 0.88$.

	Experiment	AdS_5
M_N (MeV)	940	1140
$\sqrt{\langle r_{E,S}^2 \rangle}$ (fm)	0.79	0.94
g_A	1.25	1.0
$\mu_p - \mu_n = 2\mu_V$	4.7	3.9

Table 2
Prediction of the anomalous partial decay widths in MeV where M_5, L and α have been determined from the experimental values of $F_\pi = 87$ MeV, $m_\rho = 775$ MeV and $F_\omega/F_\rho = 0.88$.

	Experiment	AdS_5
$\Gamma(\omega \to \pi\gamma)$	0.75	0.86
$\Gamma(\omega \to 3\pi)$	7.6	6.1
$\Gamma(\rho \to \pi\gamma)$	0.068	0.072
$\Gamma(\omega \to \pi\mu\mu)$	8.2×10^{-4}	7.9×10^{-4}
$\Gamma(\omega \to \pi ee)$	6.5×10^{-3}	7.8×10^{-3}

Table 3
Global fit of mesonic and baryonic physical quantities. Masses, decay constants and widths are given in MeV. The RMS error of the fit is 16%. Physical masses have been used in the kinematic factors of the partial decay widths.

	Experiment	AdS_5	Deviation
m_ρ	775	850	+10%
m_{a_1}	1230	1390	+13%
m_ω	782	850	+9%
F_ρ	153	175	+14%
F_ρ/F_ω	0.88	0.90	+2%
F_π	87	91	+5%
$g_{\rho\pi\pi}$	6.0	5.4	−10%
L_9	6.9×10^{-3}	6.2×10^{-3}	−10%
L_{10}	-5.5×10^{-3}	-6.2×10^{-3}	+12%
M_N	940	1180	+25%
$\sqrt{\langle r^2_{E,S} \rangle}$ (fm)	0.79	0.87	+21%
g_A	1.25	0.98	−21%
$\mu_p - \mu_n$	4.7	3.7	−22%
$\Gamma(\omega \to \pi\gamma)$	0.75	0.82	+10%
$\Gamma(\omega \to 3\pi)$	7.5	7.1	−6%
$\Gamma(\rho \to \pi\gamma)$	0.068	0.072	+5%
$\Gamma(\omega \to \pi\mu\mu)$	8.2×10^{-4}	7.4×10^{-4}	−9%
$\Gamma(\omega \to \pi ee)$	6.5×10^{-3}	7.4×10^{-3}	+14%

Completing the framework of AdS/QCD: h_1/b_1 mesons and excited ω/ρ's

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Abstract: We extend the "hard wall" gravity dual of QCD by including tensor fields b_{MN} that correspond to the QCD quark bilinear operators $\bar{q}\sigma^{\mu\nu}q$. These fields give rise to a spectrum of states which include the h_1 and b_1 mesons, as well as a tower of excited ω/ρ meson states. We also identify the lowest-dimension term which leads to mixing between the new ρ states and the usual tower of ρ mesons when chiral symmetry is broken.