Magnetic Phenomena in Holographic QCD

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Based on work with
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Introduction

Holographic techniques can be used to study interesting strongly coupled field theory phenomena.

Can be a laboratory of testing ideas or getting new ones.

One identifies a brane configuration whose weak coupling excitations is as close to the one we are interested. Then the large number of such branes can be exchanged for a certain background geometry.

Many physical properties can be easily computed: Phase diagram, transport properties, collective excitations...

Some effects have an easier representation: chiral symmetry breaking, effects of anomaly.

We wish to study four dimensional strongly interacting fermions.

Use the D4-D8 brane system, where the lowest excitations has only chiral fermions. (Sakai&Sugimoto)

N-D4 branes at strong 't Hooft coupling, can be studied using holographic techniques, by representing them as a curved ten-dimensional background, dual to the five dimension SU(N_c) gauge theory compactified on a circle.

Properties of the system are encoded in the world volume action of a probe D8-brane. Adding also anti D8-branes gives both left and right handed fermions.

The background D4-branes can be either in a confined or deconfined phase.

In the deconfined phase, with $\mathbf{N_f}$ D8-branes the fermions can be in a chiral symmetric phase, or a chiral broken phase. (ASY, PS)

The world volume fields living on the D8-branes encode physical properties of the fermions

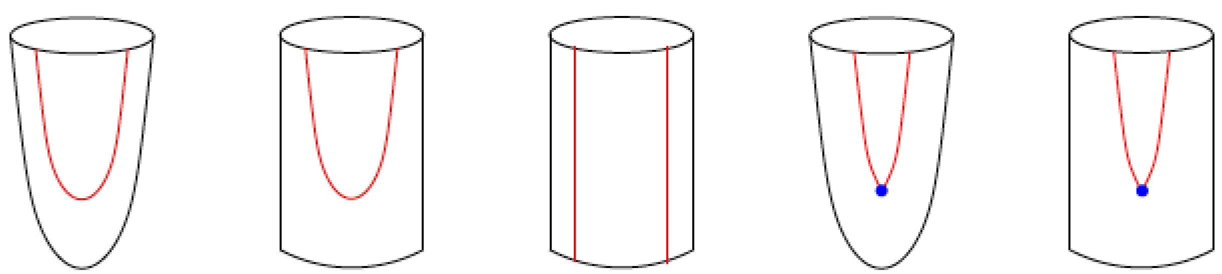
U(1) gauge field $\longleftrightarrow$ global baryon current.

In the chiral symmetric phase quarks sit at the horizon. In chiral broken phase baryonic matter is represented by wrapped D4 branes.

$$
\begin{aligned}
ds^2_{con} &= u^{\frac{3}{2}}\left(-dx_0^2+d\mathbf{x}^2+f(u)dx_4^2\right)+u^{-\frac{3}{2}}\left(\frac{du^2}{f(u)}+u^2d\Omega_4^2\right)\\
e^{\Phi} &= g_s u^{3/4}\,,\; F_4=3\pi(\alpha')^{3/2}N_c\,d\Omega_4\,,
\end{aligned}
$$

$$f(u)=1-(u_{KK}^3/u^3) \qquad\qquad f(u)=1-(u_T^3/u^3)$$

$$
\begin{aligned}
S_{DBI} &= -\mathcal{N}\int d^4x\,du\,u^{1/4}\sqrt{-\det(g_{MN}+f_{MN})}\\
S_{CS} &= -\frac{\mathcal{N}}{8}\int d^4x\,du\,\varepsilon^{MNPQR}a_M f_{NP} f_{QR}\,.
\end{aligned}
$$



Interesting phenomena

In the presence of a magnetic field F_{23} and non zero charge the world volume of the D8 branes include a DBI and a CS term. This gives some new interesting phenomena:

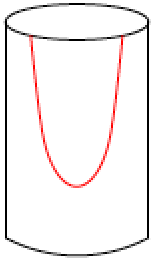
Magnetic Catalasis

New form of Baryonic matter

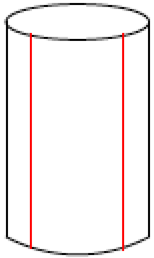
Anomalous currents

Anomalous conductivities

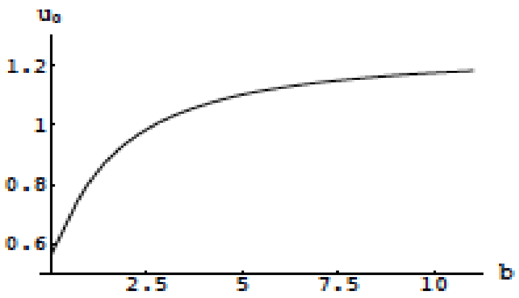
Magnetic phase transition



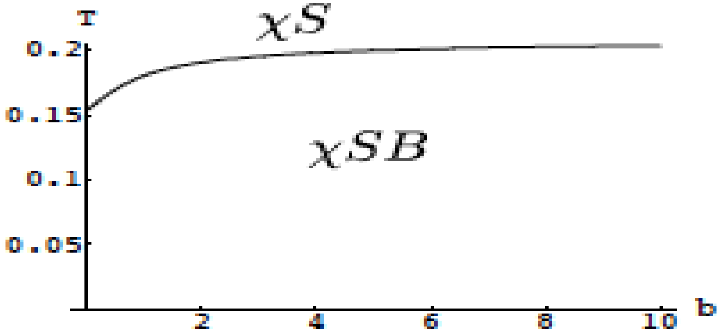
Magnetic Catalasis



The transition from chiral symmetric phase to chiral broken phase in enhanced by magnetic field.



a



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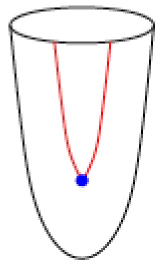


New baryonic phase

Due to the chiral anomaly, gradient of eta' carries baryonic charge (agrees with Son-Stephanov at small B and vanishing quark mass)

$$S_{DBI}^{con} = -\mathcal{N} \int_{u_{KK}}^{\infty} d^4x\, du\, u^{5/2} \sqrt{\left(\frac{1}{f(u)} - (a_0^{V\prime})^2 + (a_1^{A\prime})^2\right)\left(1 + \frac{b^2}{u^3}\right)}$$

$$S_{CS} + S_{\partial} = -\mathcal{N} \int d^4x\, du \left[\frac{3}{2} b (a_0^V a_1^{A\prime} - a_0^{V\prime} a_1^A) - \frac{1}{2} a_3^{V\prime} (a_0^V \partial_2 a_1^A - \partial_2 a_0^V a_1^A)\right]$$

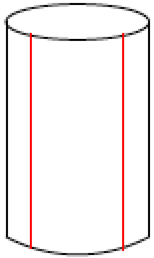
$$\frac{\sqrt{u^5 + b^2 u^2}\, a_0^{V\prime}(u)}{\sqrt{\frac{1}{f(u)} - (a_0^{V\prime}(u))^2 + (a_1^{A\prime}(u))^2}} = -3b a_1^A(u) + N_c n_{D4}$$

$$\frac{\sqrt{u^5 + b^2 u^2}\, a_1^{A\prime}(u)}{\sqrt{\frac{1}{f(u)} - (a_0^{V\prime}(u))^2 + (a_1^{A\prime}(u))^2}} = -3b a_0^V(u) + c\,,$$

$$D = \frac{N_c}{4\pi^2 f_{\eta'}} \vec{B} \cdot \vec{\nabla} \eta'$$

$$\vec{\nabla}\eta' \approx \frac{N_c}{4\pi^2 f_{\eta'}} \mu_V^{phys} \vec{B}$$

Can also have a mixed phase.



Anomalous currents

In chiral symmetric phase in consistent anomaly formulation,

$$S_{DBI}^{dec} = -\mathcal{N}\int_{u_T}^{\infty} d^4x\,du\,u^{5/2}\sqrt{\left(1-(a_0^{V\prime})^2+f(u)(a_1^{A\prime})^2\right)\left(1+\frac{b^2}{u^3}\right)}$$

$$J^{\mu}_{V,A} = \frac{\partial S_{D8}|_{on-shell}}{\partial A_{\mu}^{V,A}(u\to\infty)}$$

$$\vec{J}_A = \frac{N_c}{4\pi^2}\mu_V^{phys}\vec{B} \qquad\qquad \vec{J}_V = \frac{N_c}{4\pi^2}\mu_A^{phys}\vec{B}$$

Still some confusion about Bardeen terms (Rebhan Schmitt Stricker).

Anomalous conductivity

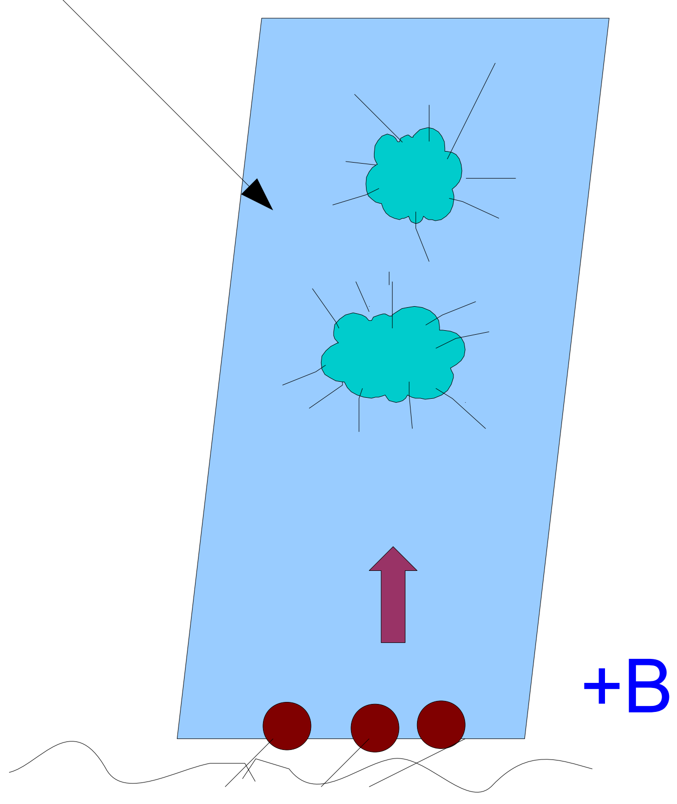
In deconfined phase with chiral symmetry, and with Magnetic field. Some of the charge goes up from the horizon in the form of smeared D4-branes. Total baryonic charge they carry is

$$d_* = -3ha_1(u_T)$$

With E ⊥ B

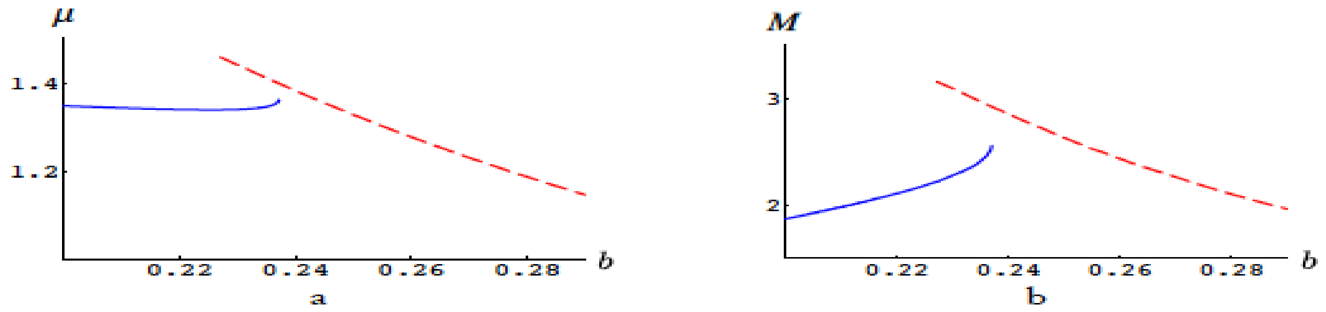
$$\sigma_L = \frac{\sqrt{u_T^8 + b^2 u_T^5 + u_T^3 (d - d_*)^2}}{u_T^3 + b^2}$$

$$\sigma_T = \frac{b(d - d_*)}{u_T^3 + b^2} + \frac{d_*}{b},$$



Magnetic Phase transition

The movement of charge upwards is discontinuous for small enough temperature, or large enough magnetic field. This is a first order phase transition.



The high magnetic field phase has

$$\mu = \frac{d}{3b} \;,\; F = \frac{d^2}{6b}$$

which signals a jump to the transverse LLL.

This phase is preferred for large d,b giving IMC. (Preis-Rebhan-Schmitt)