Top down model with baryon density: Introduction

Yunseok Seo

CQUeST

February 28, 2011

Based on
JHEP 0804:010: YS, Sang-Jin Sin
JHEP 1003:074: Youngman Kim, YS, Sang-Jin Sin
JHEP 1003:115: YS, Jonathan P. Shock, Dimitrios Joakos, Sang-Jin Sin
arXiv:1011.0868: Youngman Kim, YS, Ik Jae Shin, Sang-Jin Sin
On going work: Kwanghyun Jo, YS, Sang-Jin Sin/ Bogeun Gwak, Minkyoo Kim, Bum-Hoon Lee, YS, Sang-Jin Sin

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- Background geometry(D3/D-instanton)
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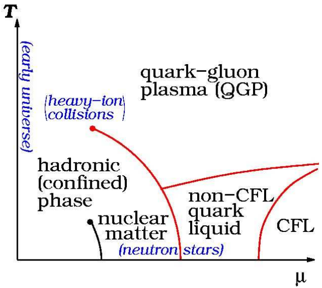
Motivation



- We are interested in understanding of QCD diagram

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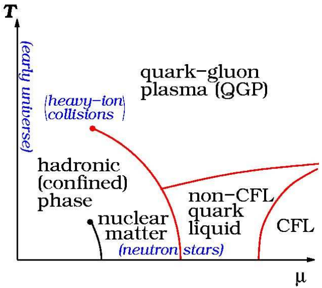

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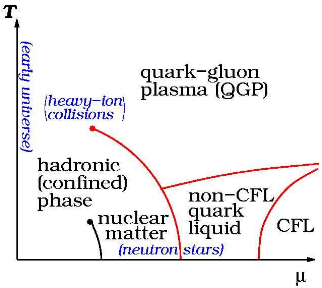

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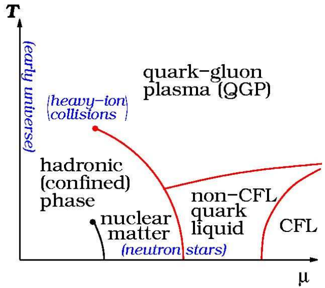

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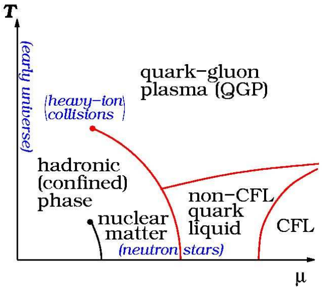

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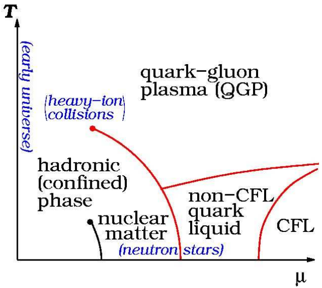
- Strongly coupled system $\longrightarrow$ breakdown of perturbative calculation
- QCD with finite density is very hard to understand even in lattice theory
  - Chiral symmetry breaking $\leftrightarrow$ confinement breaking?
  - What's the density dependence of hadronic properties? (B-R scaling...)



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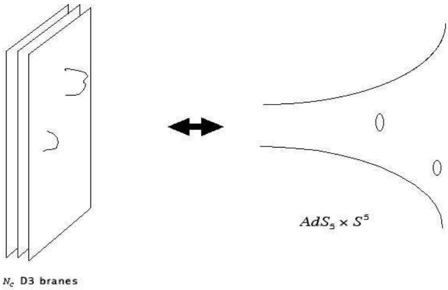
- Strongly coupled system → breakdown of perturbative calculation
- QCD with finite density is very hard to understand even in lattice theory
  - Chiral symmetry breaking ↔ confinement breaking?
  - What's the density dependence of hadronic properties? (B-R scaling...)
- Holographic QCD based on AdS/CFT may help to understand strongly interacting system with finite density

AdS/CFT correspondence

- String theory

Open Strings	Closed Strings
massless excitation Gauge Filed A_μ	massless excitation Graviton $G_{\mu\nu}$
D-branes	Curved spacetime
low energy limit $\mathcal{N} = 4,\ D = 4$ SYM	low energy limit 10d Supergravity
Large N limit Super conformal Theory	Near horizon limit $AdS_5 \times S^5$

- There is Open-Closed string duality



- Weak coupling limit ($\lambda << 1$): $\mathcal{N} = 4$, $D = 4$, $SU(N_C)$ SYM
- Strong coupling limit ($\lambda >> 1$): Classical gravity in $AdS_5 \times S^5$
- From calculating classical gravity, we can obtain some quantities in gauge theory with strong coupling.

- AdS/CFT dictionary

Gauge Theory(boundary)	Gravity(bulk)
Operator $\mathcal{O}$ (Energy momentum tensor $T_{\mu\nu}$)	Field ϕ (Graviton $g_{\mu\nu}$)
Source J	Non-normailzable mode ϕ_o
Expectation value $< \mathcal{O} >$	Normalizable mode
Conformal dimension Δ_ϕ	mass of field m_ϕ
Flavor degrees	Probe brane
Global symmetry	Gauge symmetry
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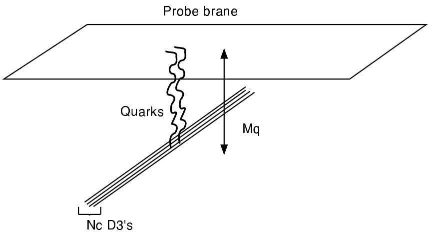
- In asymptotic region ($r \to \infty$)

$$\phi \sim J + \frac{< \mathcal{O} >}{r^\alpha} + \cdots$$

- Adding flavor



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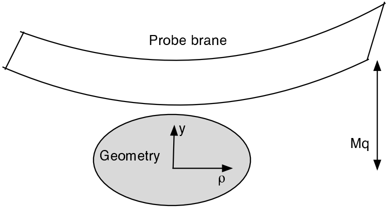

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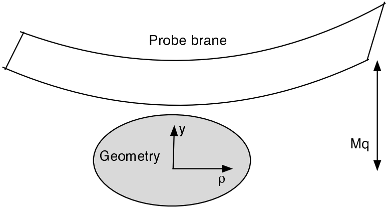

- $y(\rho) \sim M_q + \frac{<\bar{\psi}\psi>}{\rho^2} + \cdots$

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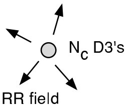

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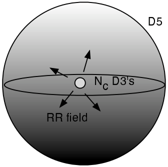

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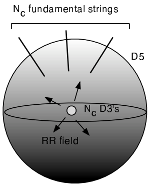

Background Geometry (D4 brane)

- Black hole geometry of D4 brane

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\begin{aligned}
ds^2 &= \left(\frac{U}{R}\right)^{3/2}\left(f(U)dt^2 + d\vec{x}^2 + dx_4^2\right) + \left(\frac{R}{U}\right)^{3/2}\left(\frac{dU^2}{f(U)} + U^2 d\Omega_4^2\right) \\
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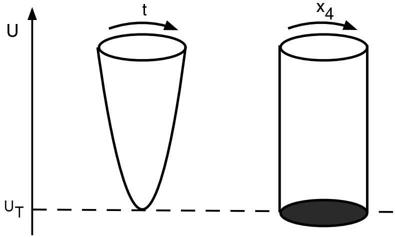

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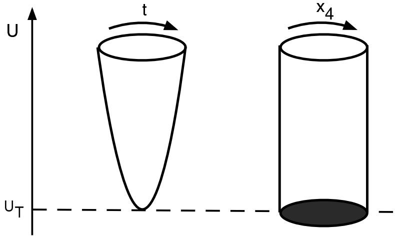
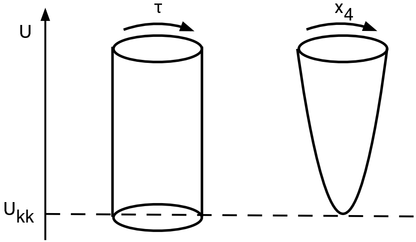


- Doulbe Wick'ed geometry



- Putting $D6$ brane as probe

	x^0	x^1	x^2	x^3	x^4	x^5	x^6	x^7	x^8	x^9
$D4$	•	•	•	•	•					
$D6$	•	•	•	•		•	•	•		

  - Two transverse direction to probe brane $(x^8, x^9) \longrightarrow M_q$

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	x^0	x^1	x^2	x^3	x^4	x^5	x^6	x^7	x^8	x^9
$D4$	•	•	•	•	•					
$D6$	•	•	•	•		•	•	•		
$D4$(baryon)	•						•	•	•	•

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  - Adding baryon charge $\rightarrow$ quarks or baryon vertices(D4)

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$D4$	•	•	•	•	•					
$D6$	•	•	•	•		•	•	•		
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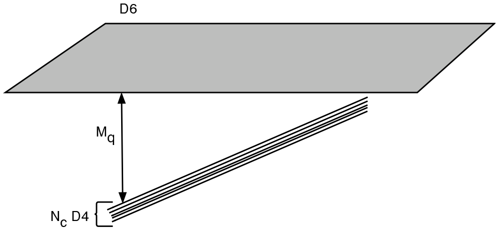
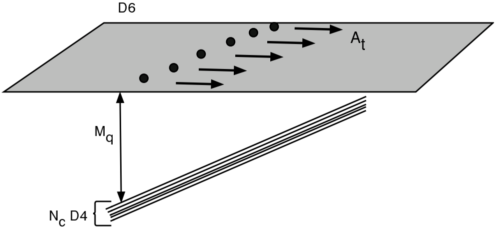


D6 Probe: Massive Quark Model

- Putting *D6* brane as probe

	x^0	x^1	x^2	x^3	x^4	x^5	x^6	x^7	x^8	x^9
D4	•	•	•	•	•					
D6	•	•	•	•		•	•	•		
D4(baryon)	•						•	•	•	•

  - Two transverse direction to probe brane $(x^8, x^9) \to M_q$
  - Adding baryon charge $\to$ quarks or baryon vertices



- Putting *D*6 brane as probe

	x^0	x^1	x^2	x^3	x^4	x^5	x^6	x^7	x^8	x^9
$D4$	•	•	•	•	•					
$D6$	•	•	•	•		•	•	•		
$D4$(baryon)	•						•	•	•	•

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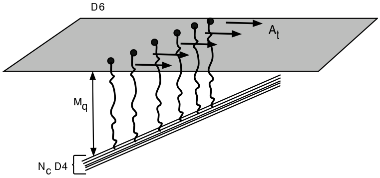

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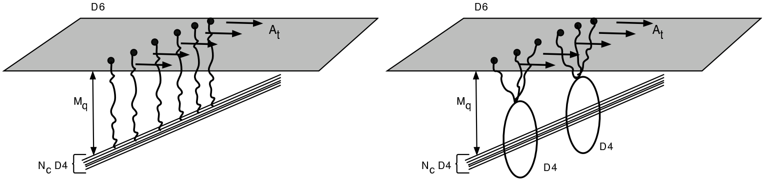

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  - Finite temperature
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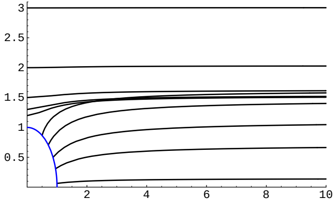

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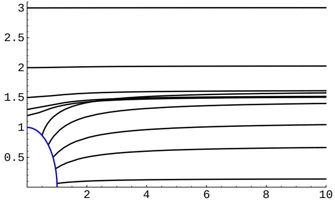

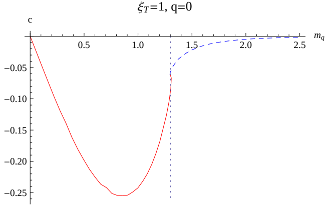

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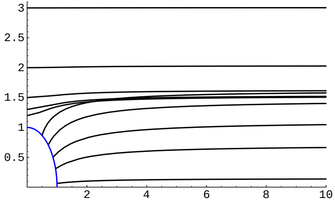
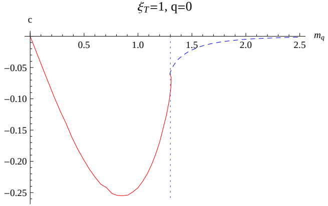
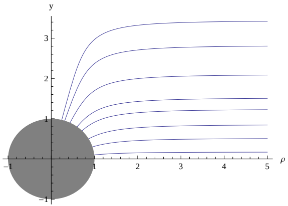




- Finite density(no baryon vertex solution)



- Double Wicked geometry
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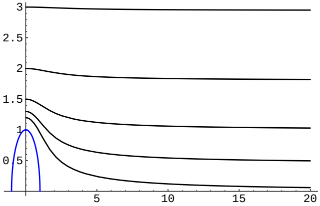
  - Confined phase
- Zero density



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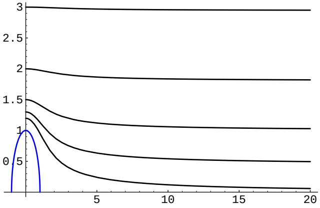

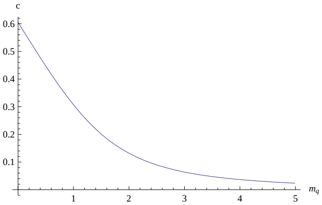

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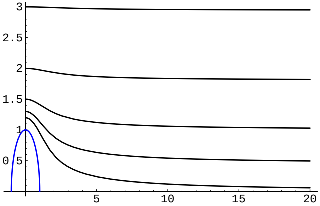
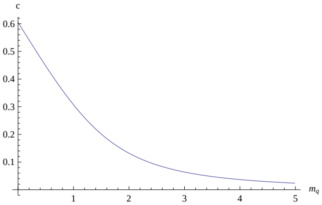
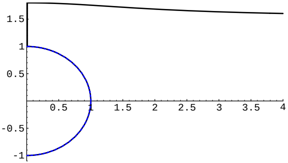




- Finite density (baryon vertex)



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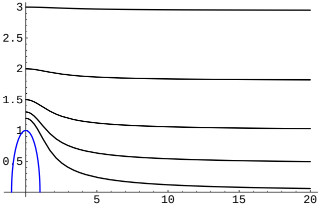

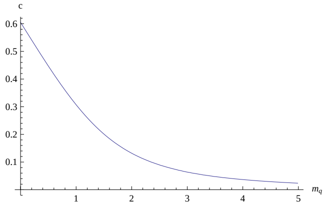

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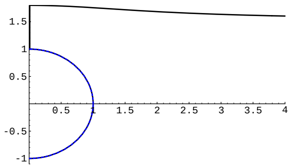
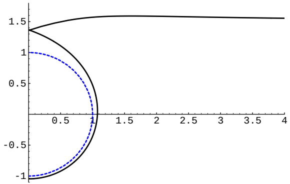
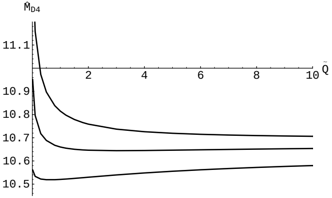




- Density dependence of mass of baryon JHEP 0804:010: YS, Sang-Jin Sin



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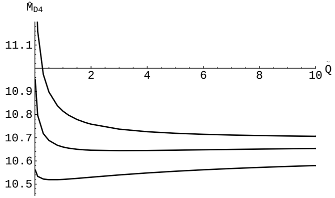
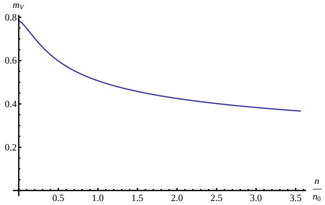
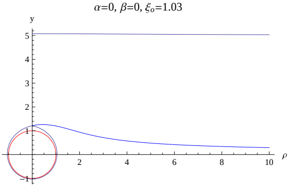


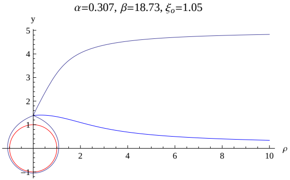
- Meson spectrum on going work: Kwanghyun Jo, YS, Sang-Jin Sin



D6 Probe: Massive Quark Model

- Two flavor system JHEP 1003:074: Youngman Kim, YS, Sang-Jin Sin





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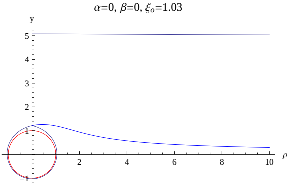
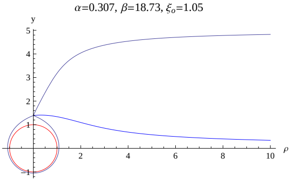
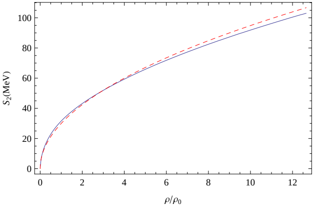




- Symmetry energy arXiv:1011.0868: Youngman Kim, YS, Ik Jae Shin, Sang-Jin Sin



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  - Black hole horizon at $r = r_T$ $\rightarrow$ Finite temperature
  - q is proportional to value of gluon condensation $< F^2 >$
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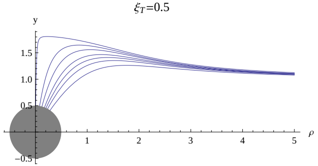
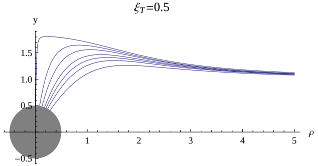
  - D7 brane used as flavor brane

- Quark phase



Phase transition

- Quark phase



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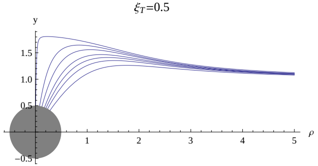

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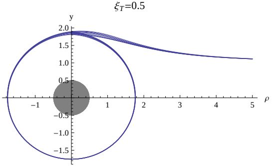

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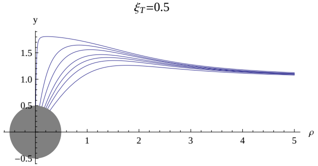

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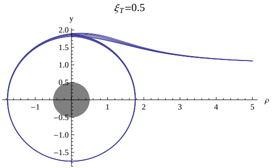

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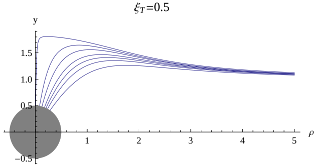

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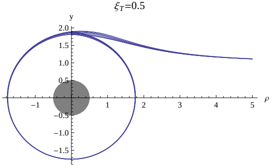

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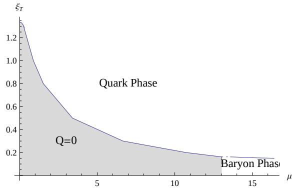
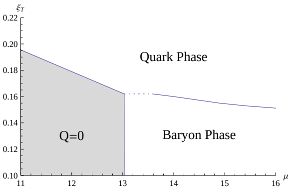
- Comparing free energy, we can determine which phase is physical for given temperature and density

- In grand canonical ensemble On going work: Bogeun Gwak, Minkyoo Kim, Bum-Hoon Lee, YS, Sang-Jin Sin





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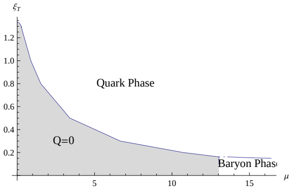

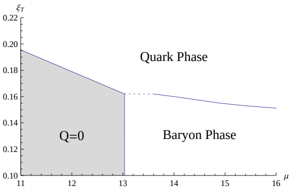

- Chiral transition = confinement/deconfinement transition
- Relation between chiral condensation and gluon condensation
- Fluctuation spectrum

Conclusion and Discussion

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- Baryon spectrum
- Application to condensed matter physic
- Beyond probe limit?

Thank you !!!