Dynamical Holographic QCD Model for Chiral Symmetry Breaking and Confinement

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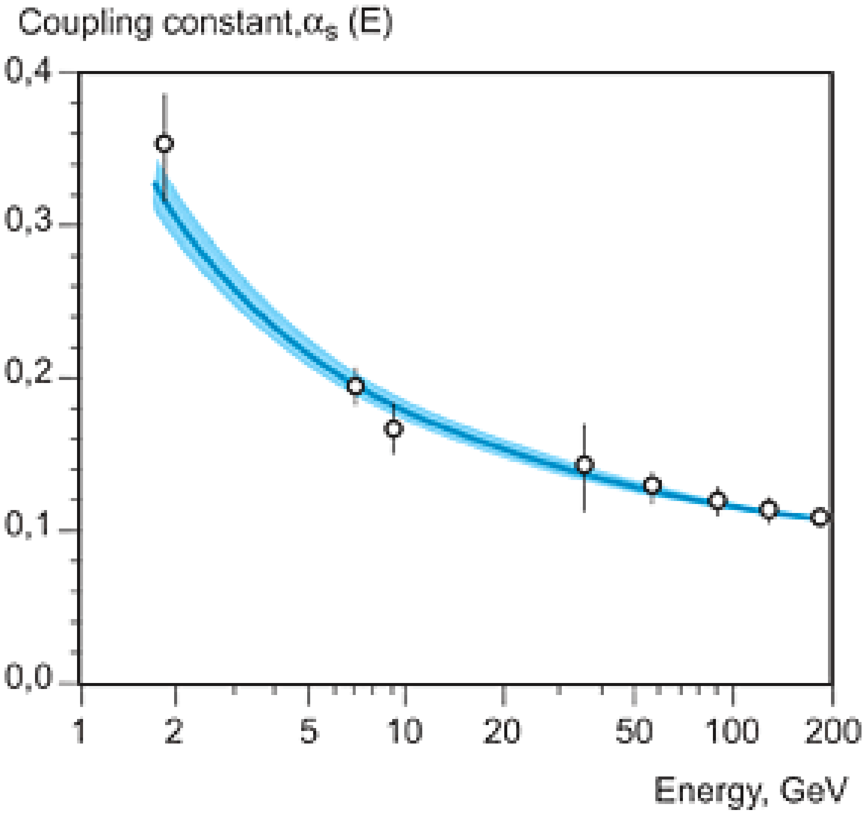
Beihang, Oct, 28, 2013

Outlines

- I.A brief introduction to holographic QCD
- II.Graviton-Dilaton system and pure gluon system
- III. Accommodate chiral symmetry breaking and linear confinement in a dynamical holographic QCD model
- IV.Conclusion

I.A brief introduction to holographic QCD

Why holographic QCD?



Perturbation calculation fails in low energy region

Non-perturbative methods:
Lattice simulation, DSE,FRG, Effective field theory…

Holographic QCD method:
analytic understanding, easier calculation

AdS/CFT Correspondence

Juan Maldacena, Adv.Theor.Math.Phys.2:231-252,1998

Two Descriptions for the N D3-Branes stack

Decoupled:A1+B1

A1:Strongly coupled gauge theory

B1:Super gravity in flat spacetime

$\lambda = g_{YM}^2 N = 4\pi g_s N >> 1$

Decoupled:A2+B2

A2:Closed strings in AdS background

B2:Super gravity in flat spacetime

$\frac{R^4}{l_s^4} = 4\pi g_s N_c >> 1$

Conjecture:Duality of the two theories

Equivalence of the partition function:

$$< e^{\int \phi_0^i O_i} >_{CFT} = Z_{string}[\phi^i(x, z|_{boundary}) = \phi_0^i(x)] \sim e^{-S_{Gravity}}$$

Towards Realistic Models

Further Conjecture

AdS/CFT Correspondence → General Gauge/Gravity

Task: find the proper non-conformal gravity background for QCD:

Top-Down Approach:

derive the background from fundamental string theory

Bottom-Up Approach:

find the background in a phenomenological way

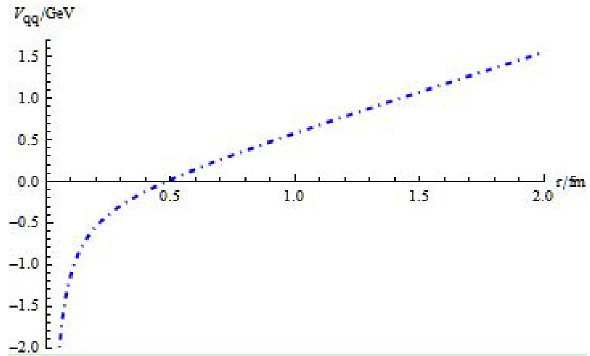
provide clues to the Top-down

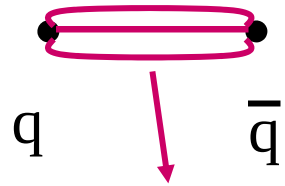
II.Graviton-Dilaton system and pure gluon system

Confinement in QCD vacuum and deconfinement at finite temperature

Zero temperature

$$V_{qq} = \frac{k}{r} + c_0 + \sigma r$$

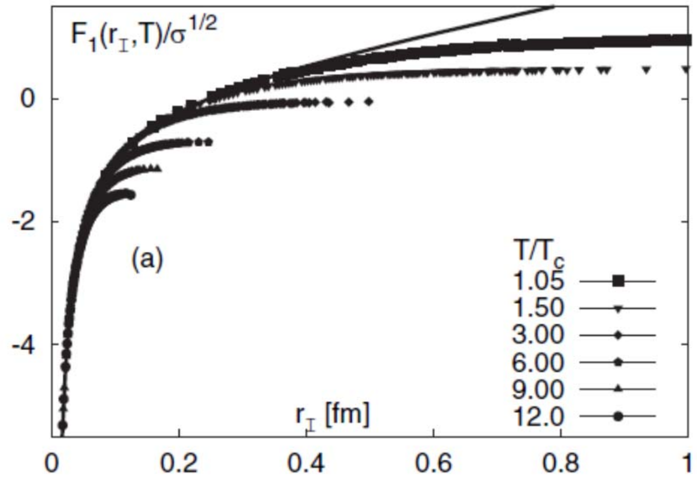




Flux tubes of color field = glue

Finite temperature:

Debye screening effect



O.Kaczmarek, F.Karsch,and F.Zantow, Phys.Rev.D.70.074505

Graviton-Dilaton System

$$S_{GD} = \frac{1}{2\kappa^2}\int dx^5 \sqrt{-g}\, e^{-2\phi}(R + 4\partial_m\phi\partial^m\phi + V_s(\phi))$$

Dynamical dilaton

deform the background metric: the warp factor

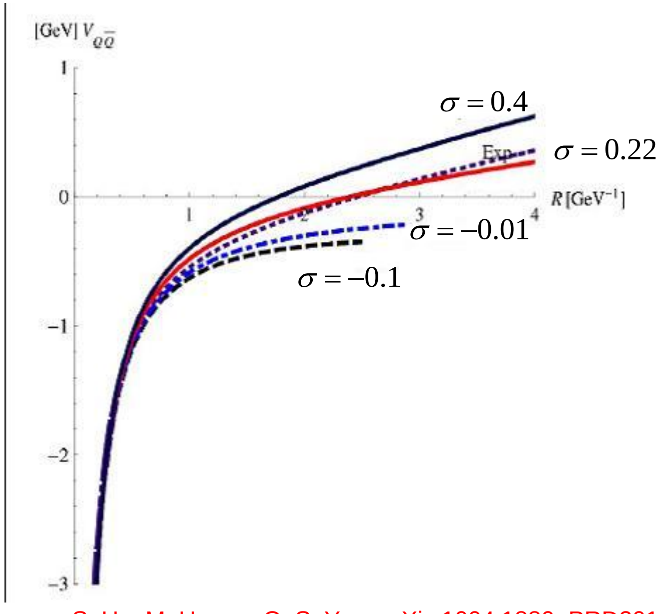
Andreev-Zakharov

Quadratic warp factor

$$A_s = \frac{\sigma z^2}{2}$$

Zero temperature:

$$dS^2 = g_{mn}dx^m dx^n = \frac{e^{2A_s}}{z^2}(-dt^2 + dz^2 + dx_i dx^i)$$



S. He, M. Huang, Q. S. Yan, arXiv:1004.1880, PRD2011

Study the finite T behavior:
Black hole solution

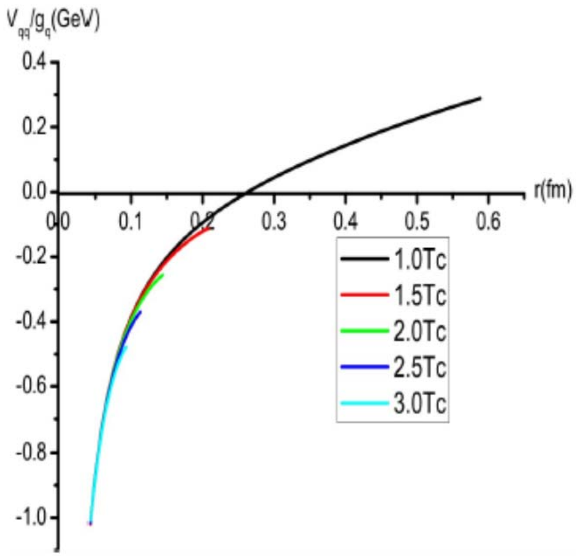
$$dS^2 = g_{mn}dx^m dx^n = \frac{e^{2A_s}}{z^2}\left(-f(z)dt^2 + \frac{1}{f(z)}dz^2 + dx_i dx^i\right)$$

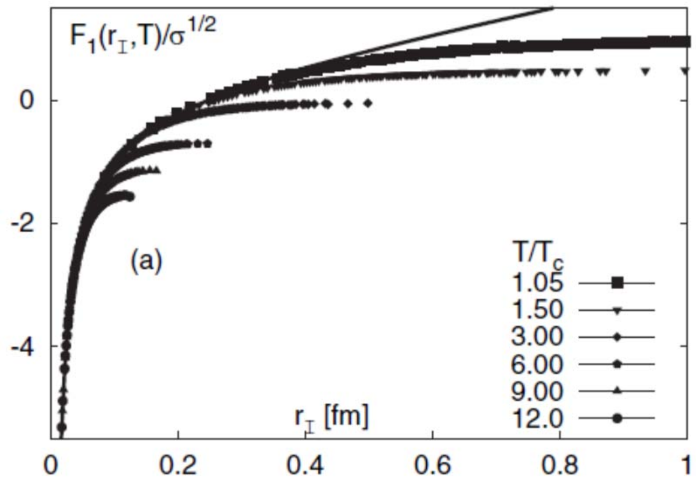
$$T = \frac{|f'(z_h)|}{4\pi}.$$

$$A_s = \frac{\sigma z^2}{2}$$

Dilaton profile and potential can be self-consistently solved from the equation of motion

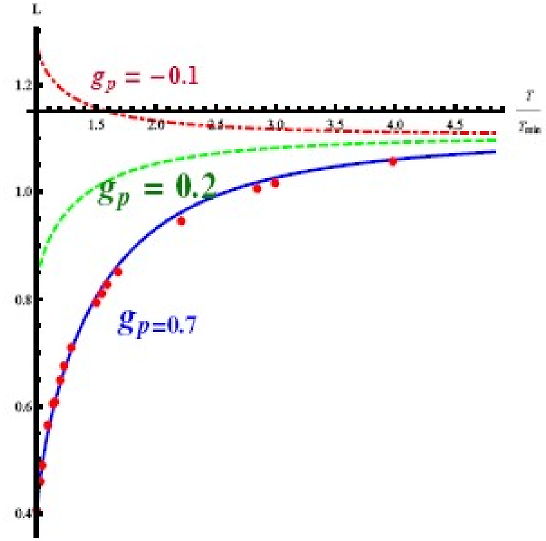
Finite temperature behavior in the gravity background



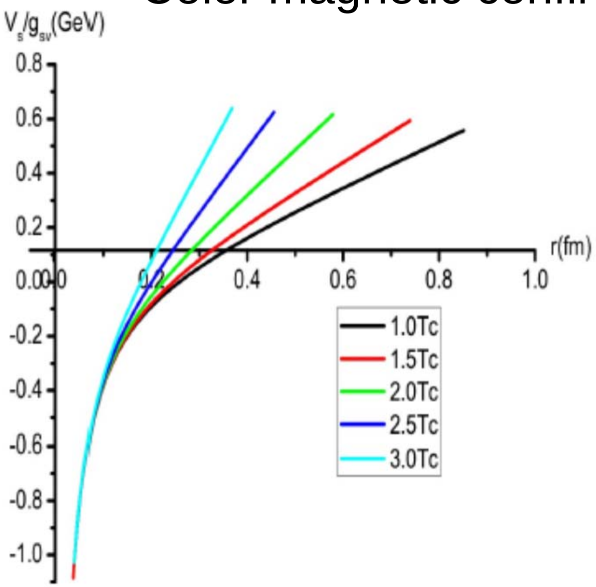


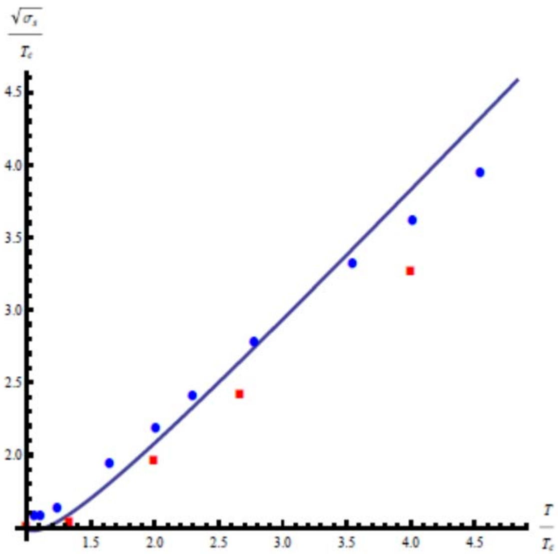
D.N. Li, S. He, M.Huang, Q. S. Yan, arXiv:1103.5389, JHEP2011 O.Kaczmarek, F.Karsch,and F.Zantow, Phys.Rev.D.70.074505

Polyakov loop:
color electric
deconfinement



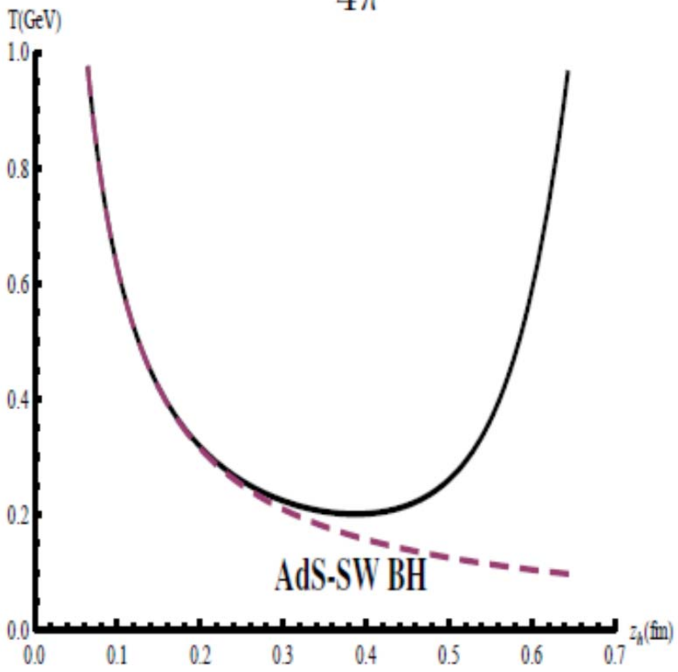
Spatial wilson loop:
Color magnetic confinement



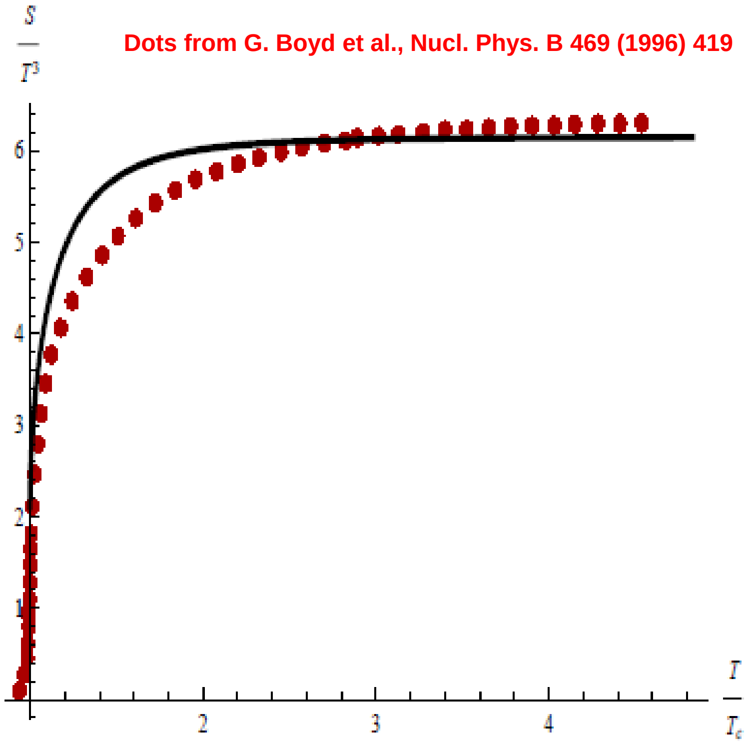


EOS V.S. Quenched Lattice Results

$$T = \frac{|f'(z_h)|}{4\pi}.$$



$$s = \frac{A_{area}}{4G_5 V_3} = \frac{L^3}{4G_5}\left(\frac{e^{A_s - \frac{2}{3}\phi}}{z}\right)^3.$$



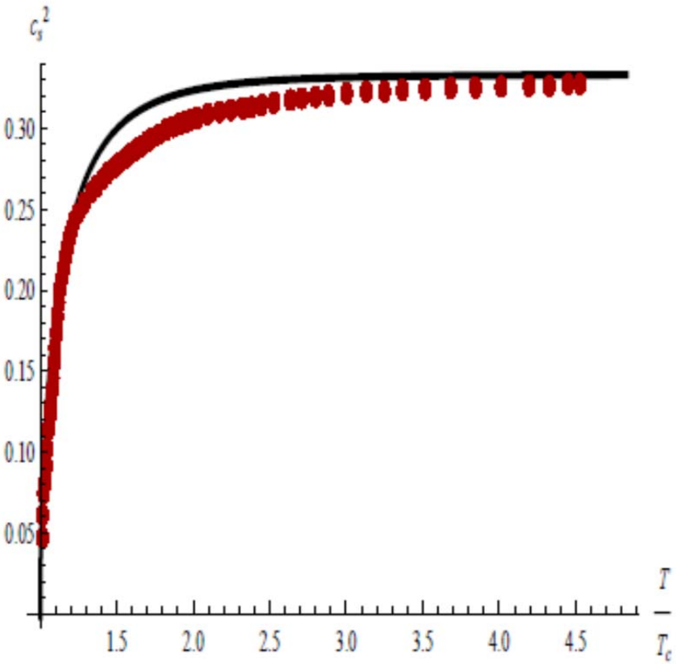
$$T_c = 201\text{MeV}$$

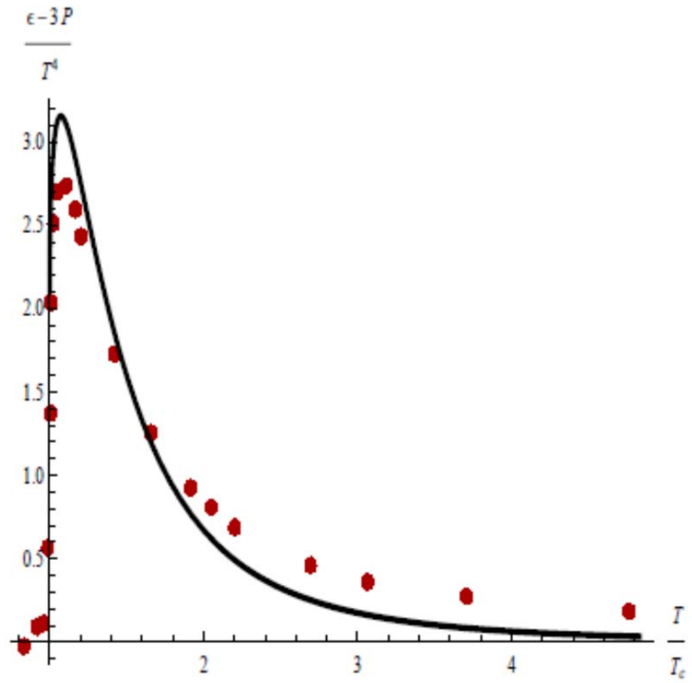
D.N. Li, S. He, M.Huang, Q. S. Yan, arXiv:1103.5389, JHEP2011

EOS V.S. Quenched Lattice Results

$$c_s^2 = \frac{d\log T}{d\log s} = \frac{s}{T ds/dT},$$

Dots from G. Boyd et al., Nucl. Phys. B 469 (1996) 419





D.N. Li, S. He, M.Huang, Q. S. Yan, arXiv:1103.5389, JHEP2011

- At zero temperature and finite temperature, such a graviton-dilaton coupled system can describe the heavy quark potential behavior very well.

- The equation of states fits the quenched lattice data well (above Tc), which indicate that such a system can describe the pure gluon dynamics.

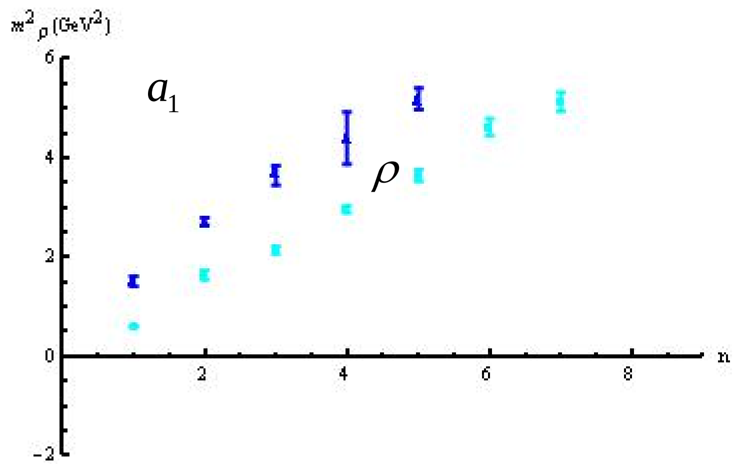
III. Accommodate chiral symmetry breaking and linear confinement in a dynamic holography QCD model

Chiral symmetry breaking and confinement from meson spectra

Chiral symmetry breaking:

Chiral condensate spontaneously breaks the chiral symmetry, and provide quarks dynamical masses.

Mass split in chiral partner



Confinement:

Linear spectra in highly excited states

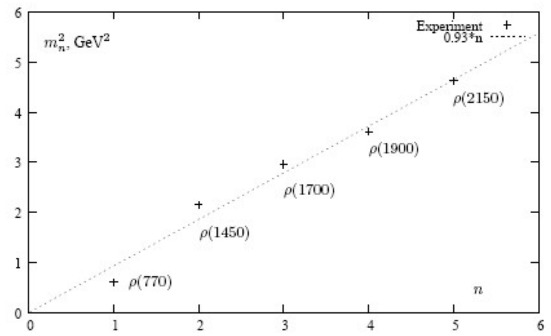
Data from C.Amsler et.al, Phys.Lett.B667(2008)1

KKSS model

Karch, Katz,Son,Stephonov, Phys.Rev.D74:015005,2006

$$S_{kkss} = \int dx^5 \sqrt{-g} e^{-\phi} [|DX|^2 + 3|X|^2 - \frac{1}{4g_5^2}(F_L^2 + F_R^2)] \quad \phi = \mu^2 z^2 \qquad m_{\rho,n}^2 = 4\mu^2 n$$

Chiral symmetry is broken by the expectation value of X

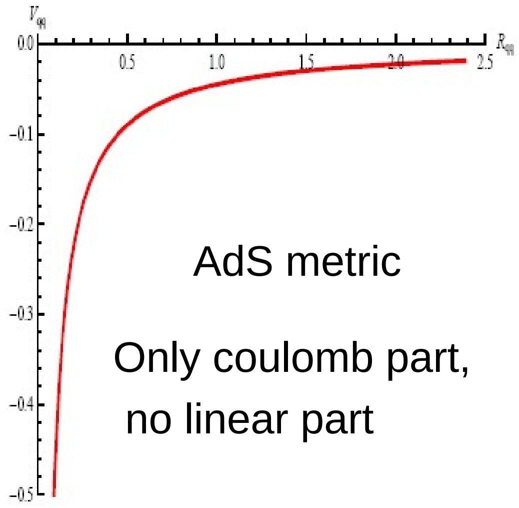


$$X = \frac{\chi}{2} I_{2\times 2}, \quad \chi = m_q\, z + \sigma\, z^3 + o(z^4)$$

$$V_\rho = \frac{A_s'' - \phi''}{2} + \frac{(A_s' - \phi')^2}{4}$$

$$V_{a_1} = \frac{A_s'' - \phi''}{2} + \frac{(A_s' - \phi')^2}{4} + g_5^2 \chi^2 e^{2A_s}$$

Chiral Symmetry breaking



A successful holographic QCD model

- should incoperate the linear potential and linear spectra (two aspects of confinement) simultaneously

- should realize chiral symmetry breaking and confinement simultaneously

Accommodate the two aspects at zero temperature

$$S = S_{GD} + \frac{N_f}{N_c} S_{KKSS}$$

Cover chiral dynamics and gluon dynamics

$$N_f = 2, N_c = 3$$

Zero temperature

$$dS^2 = e^{2A_s(z)}(-dt^2 + dz^2 + dx_i dx^i)$$

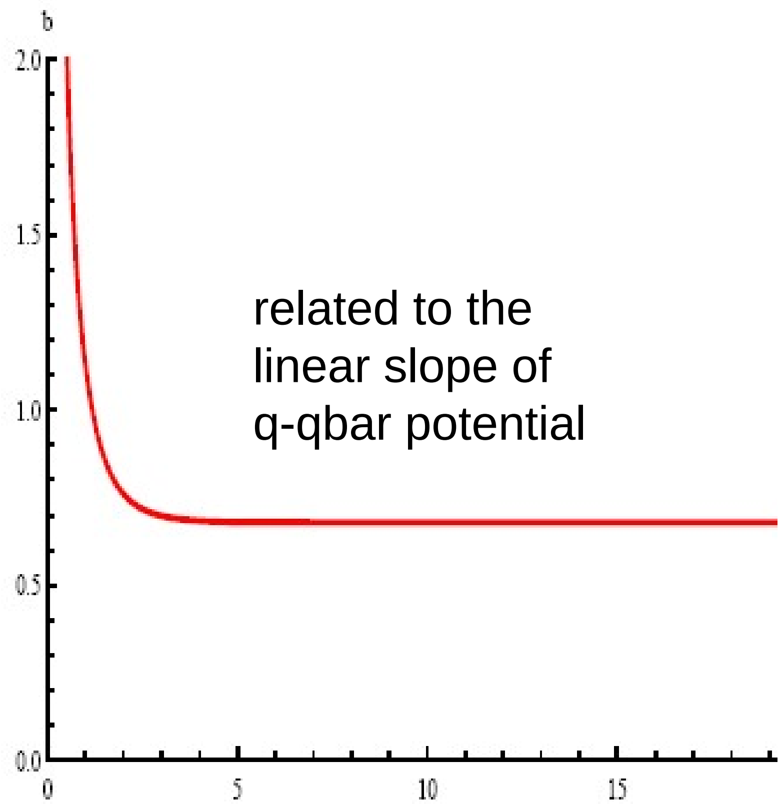
Dilaton profile

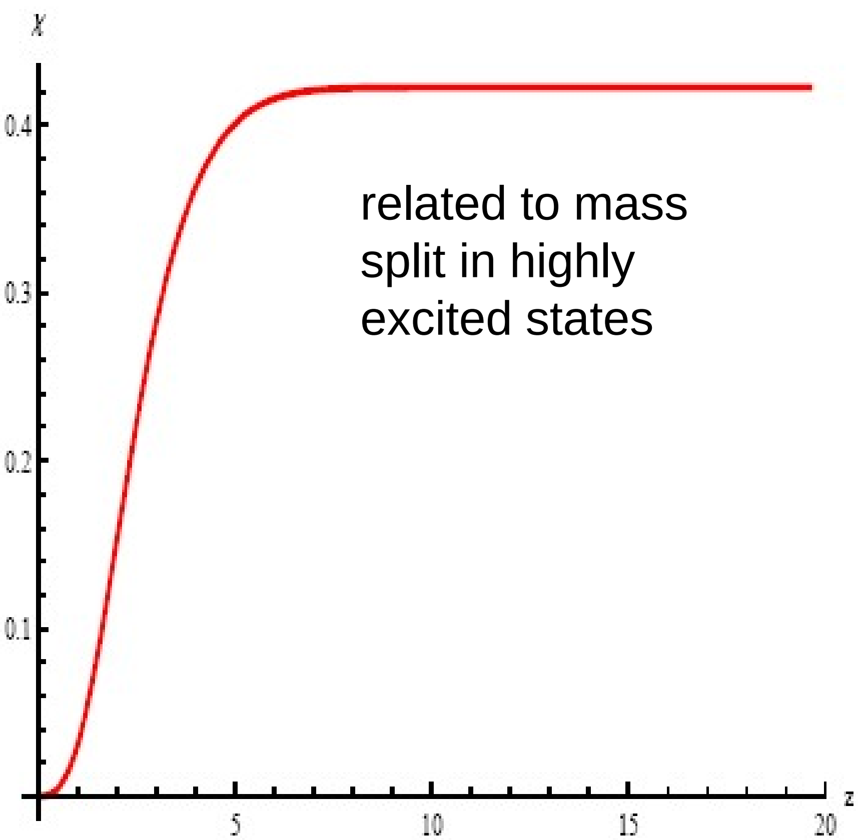
$$\phi = \mu^2 z^2$$

UV behavior of χ

$$\chi = m_q z + \sigma z^3 + o(z^4)$$

The Background Solution





D.Li, M.Huang, and Q.S.Yan, arxiv:1206.2824

Rho-a masses

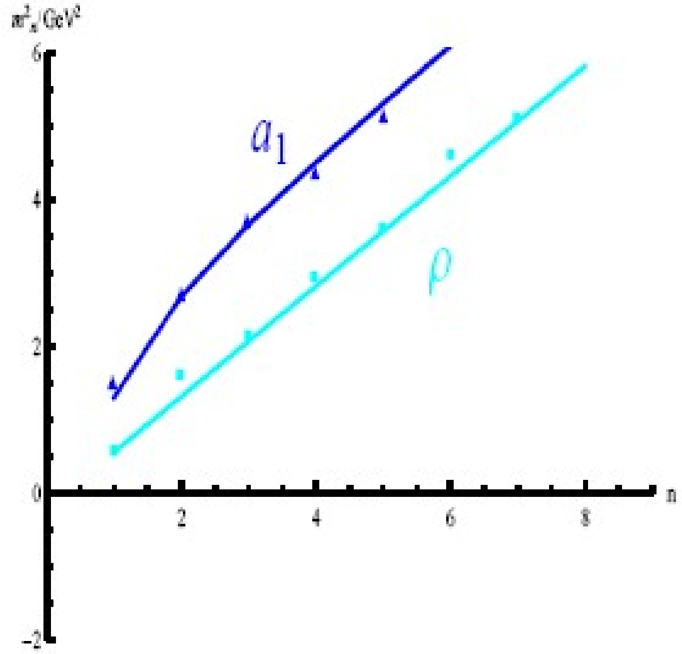
Read from the singularity point of current-current correlation fuction or equivalently by solving a group of schrodinger-like equations with 5D effective potentials

$$V_\rho = \frac{A_s'' - \phi''}{2} + \frac{(A_s' - \phi')^2}{4}$$

$$V_{a_1} = \frac{A_s'' - \phi''}{2} + \frac{(A_s' - \phi')^2}{4} + g_5^2 \chi^2 e^{2A_s}$$

The slope is $4\mu^2$

Chiral partner get a mass split



D.Li, M.Huang, and Q.S.Yan, arxiv:1206.2824

Dots from C.Amsler et.al, Phys.Lett.B667(2008)1

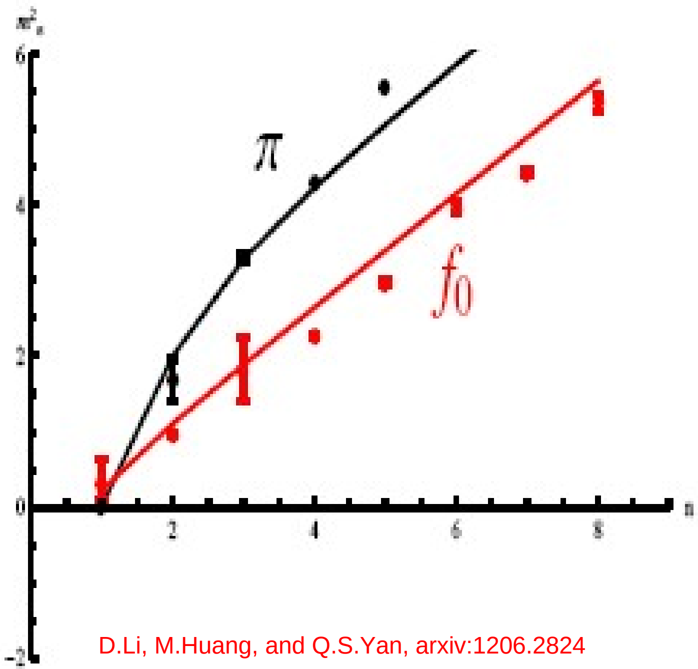
pi-f0 masses

Pion mass is small about 140 MeV

Pseudo Goldstone !!

Chiral partner get a mass split

The slope is $4\mu^2$



D.Li, M.Huang, and Q.S.Yan, arxiv:1206.2824

Dots from C.Amsler et.al, Phys.Lett.B667(2008)1

$$V_s = \frac{3A_s'' - \phi''}{2} + \frac{(3A_s' - \phi')^2}{4} + e^{2A_s}\partial_\chi^2 V(\chi);$$

$$V_s = -\frac{3A_s'' - \phi'' + 2\chi''/\chi - 2\chi'^2/\chi^2}{2} + \frac{(3A_s' - \phi' + 2\chi'/\chi)^2}{4} + g_5^2\chi^2 e^{2A_s}$$

The quark antiquark potential

The linear potential is produced.

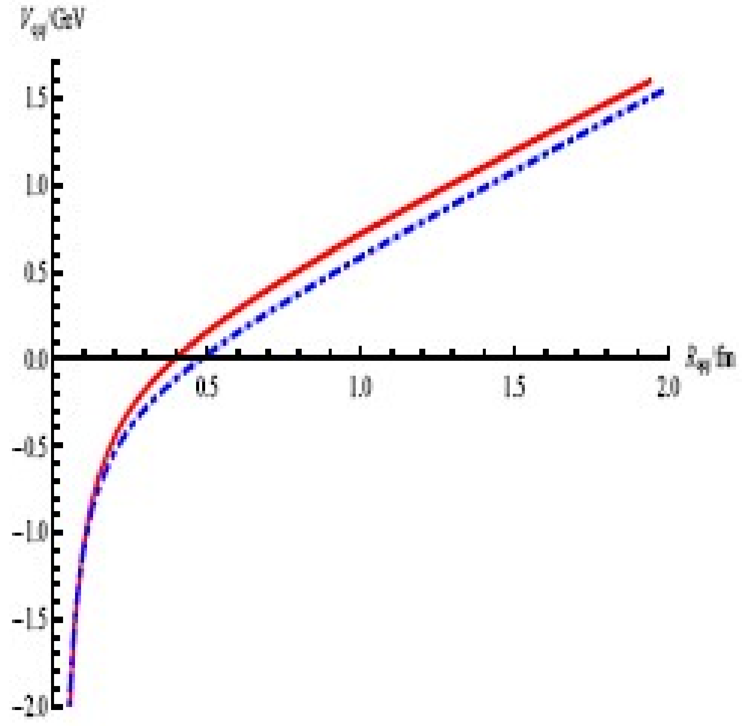
The slope of the linear part is: $\sigma_s \approx 4\mu^2$

$$\phi = \mu^2 z^2$$

$$m_\phi^2 L^2 = -4 \quad \Downarrow \quad \Delta_\phi = 2$$

Some dimension-2 operatror related to gluon dynamics ?

Need further study



D.Li, M.Huang, and Q.S.Yan, arxiv:1206.2824

IV.Conclusion

- **The graviton-dilaton system describes the pure gluon dynamics above Tc quite well.**
- **Graviton-dilaton-scalar system can cover the gluon and chiral dynamics well. In this system, we accommodate chiral symmetry breaking, linear spectra and linear potential self-consistently for the first time in holographic QCD frame. The slope of the linear potential and the linear spectra are the same and related to dilaton, which is consistent with the consideration that the two phenomena have the same origin---the gluon dynamics.**
- **Studying the confinement-deconfinement phase transition and chiral phase transition simultaneously is in progress.**

Thanks for your attention !