# Chiral Symmetry Breaking and Linear Confinement in a Dynamic Holography QCD Model

Danning Li

Institute of High Energy Physics, CAS

In collaboration with Mei Huang and Qi-Shu Yan

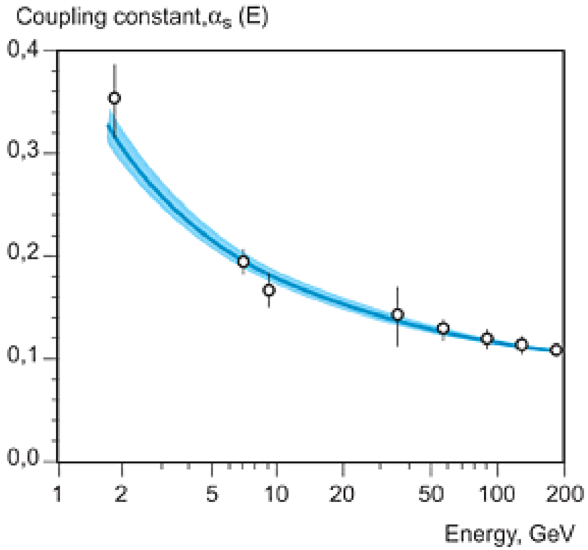
Erice, SEP, 23, 2012

# Outlines

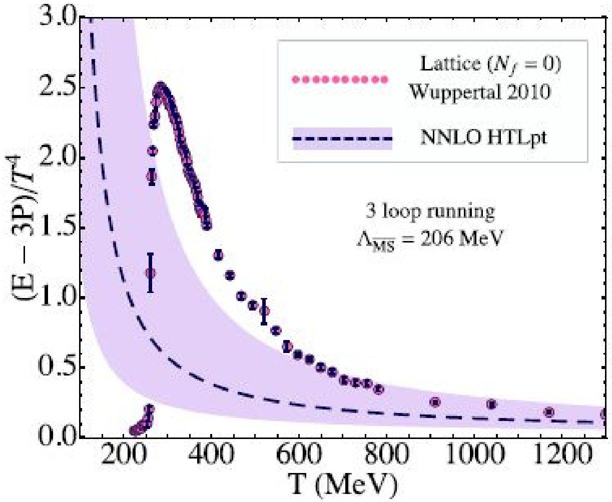
- I.A brief introduction to holography QCD
- II.Graviton-Dilaton system and pure gluon system
- III. Accommodate chiral symmetry breaking and linear confinement in a dynamic holography QCD model
- IV.Conclusion

# I.A brief introduction to holography QCD

# Why holography QCD?




Andersen, Strickland and Su, JHEP 1008, 113 (2010)




Perturbation theory fails in both zero temperature case and finite temperature case

Non-perturbative methods:
Lattice simulation, DSE, 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

Strongly coupled gauge theory

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


Closed strings in AdS background

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

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:**

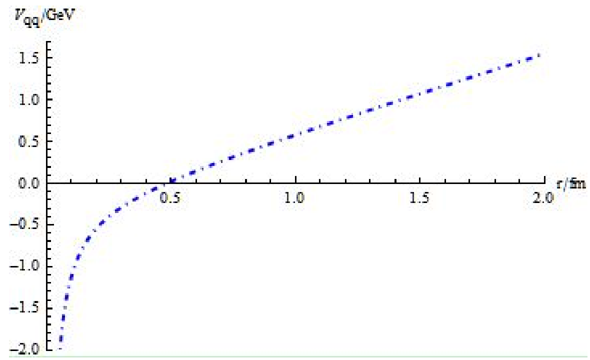
find the background in a phenomenological way
leave the origin of the background to the Top-down approach

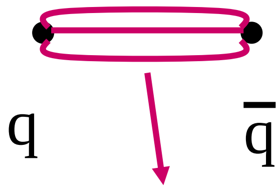
# II.Graviton-Dilaton system and pure gluon system

# Confinement in QCD vacuum and deconfinement at finite temperature

Zero temperature

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

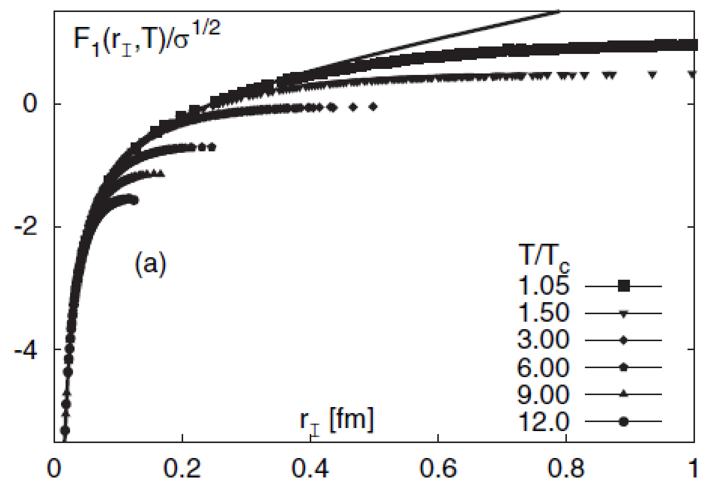



Flux tubes of color field = glue

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

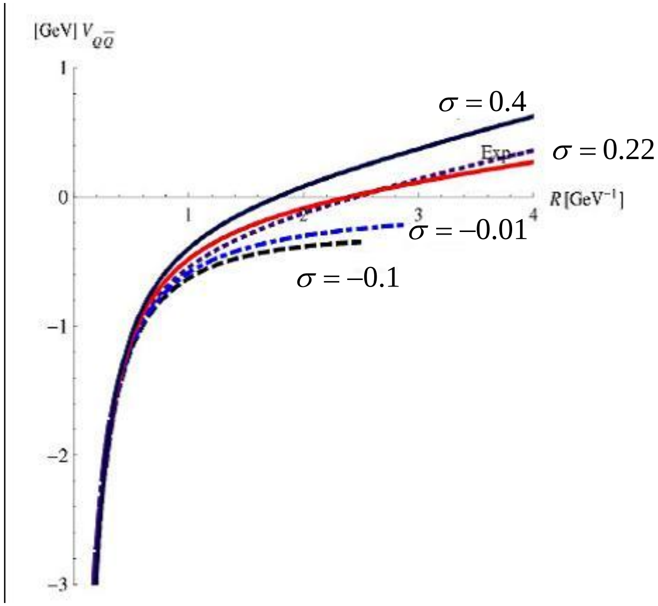
Andreev-Zakharov

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

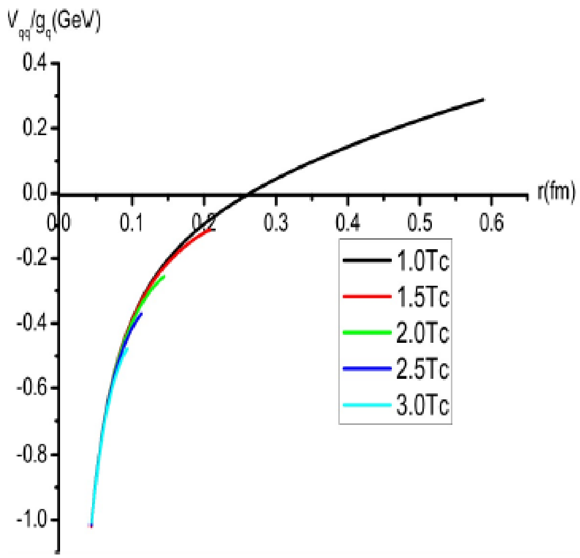
$$dS^2 = g_{mn}dx^m dx^n = \frac{e^{2A_s}}{z^2}\left(-f(z)dt^2 + \frac{1}{f(z)}dz^2 + dx_i dx^i\right)$$

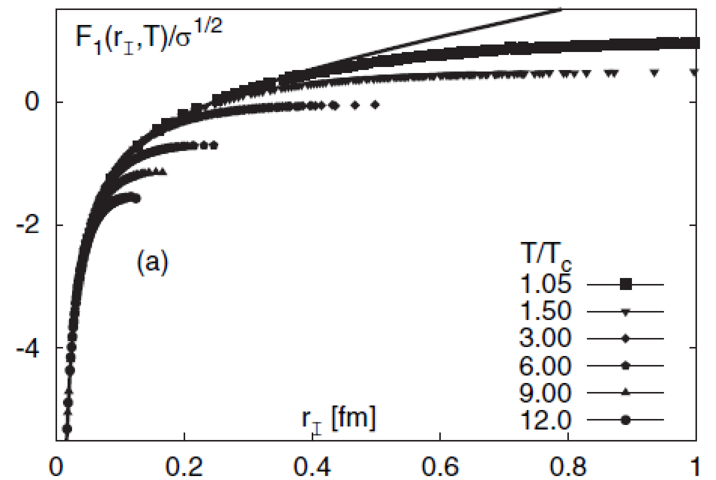
$$T = \frac{|f'(z_h)|}{4\pi}.$$

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

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

Finite temperature behavior in the gravity background

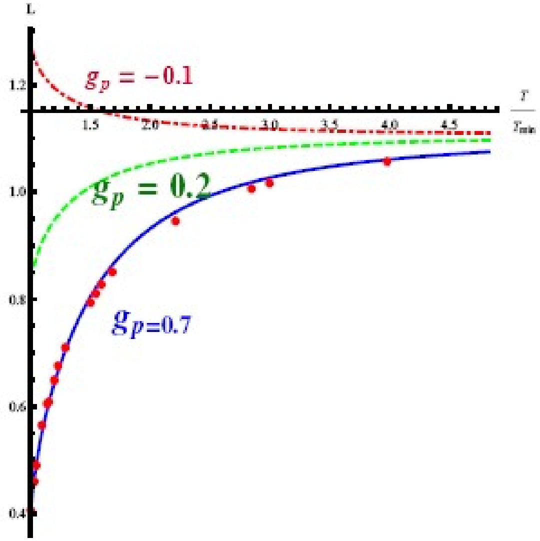


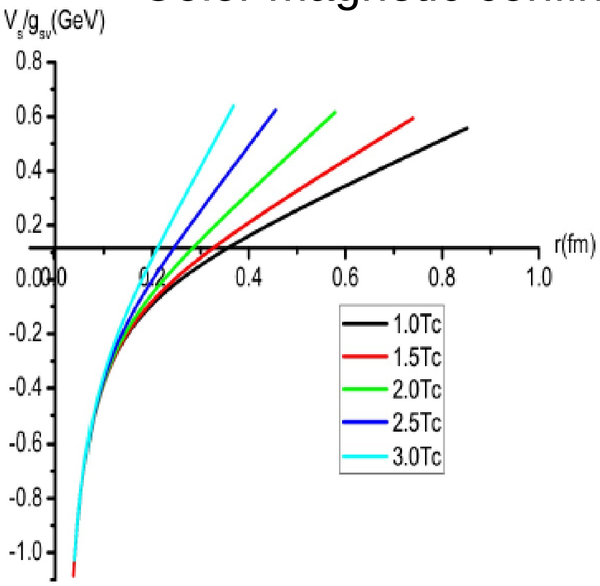

D.N. Li, S. He, M.Huang, Q. S. Yan, arXiv:1103.5389, JHEP2011

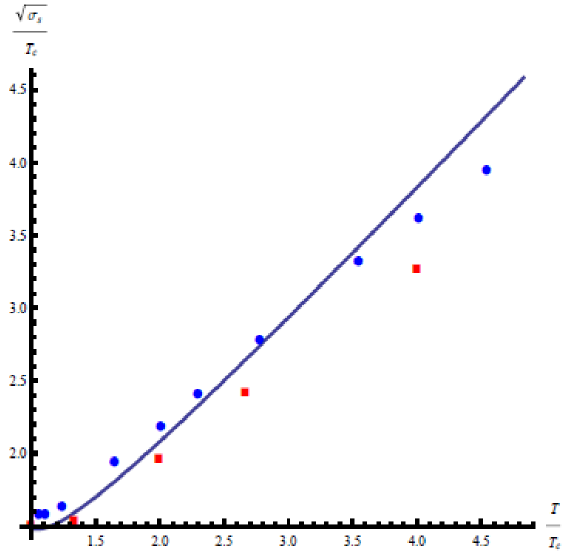
O.Kaczmarek, F.Karsch,and F.Zantow, Phys.Rev.D.70.074505

Polyakov loop:
color electric
deconfinement



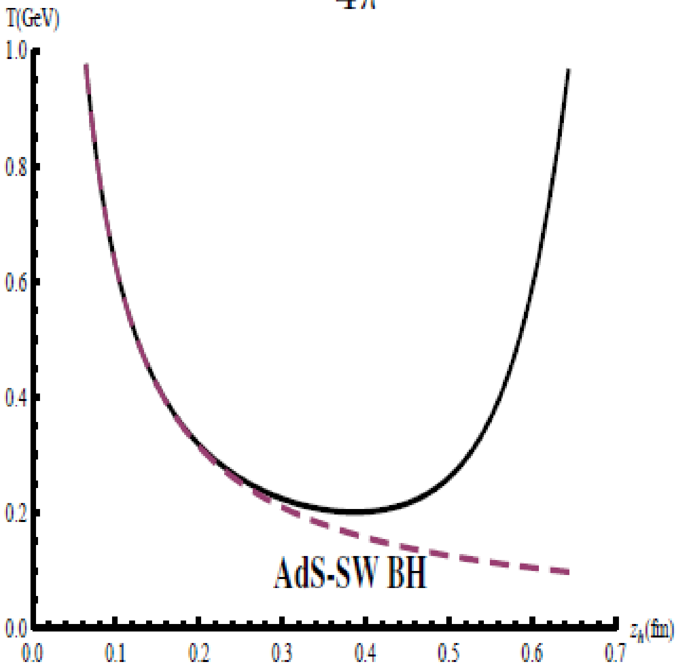

Spatial wilson loop:
Color magnetic confinement



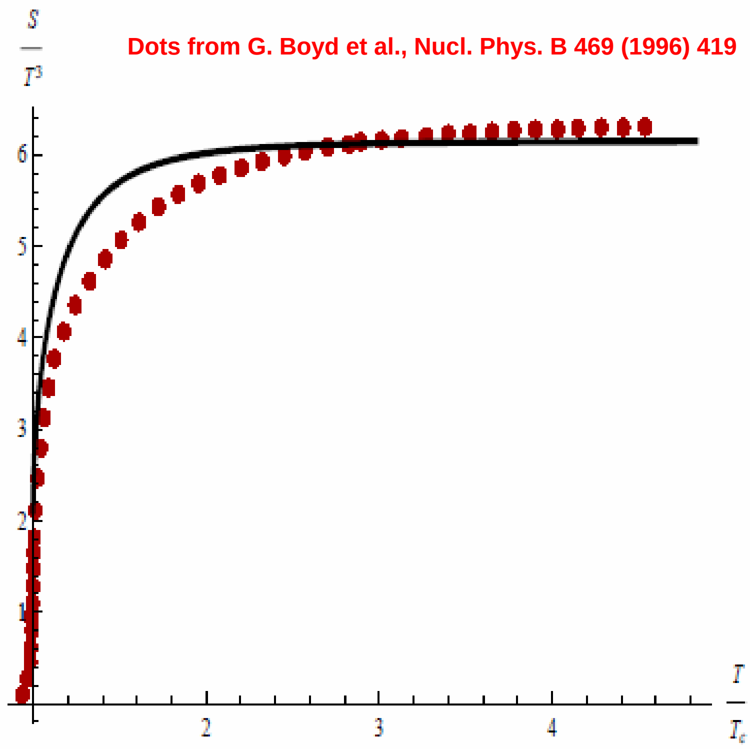



# EOS V.S. Quenched Lattice Results

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




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



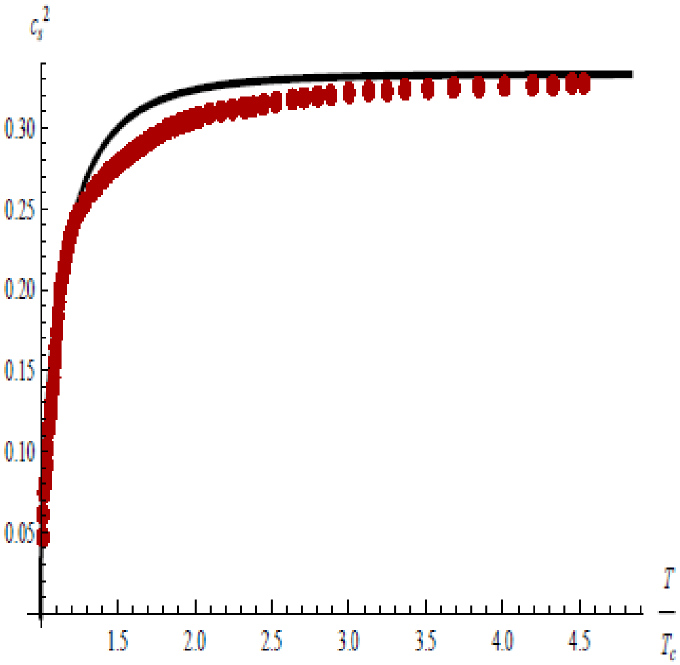

$$T_c = 201\text{MeV}$$

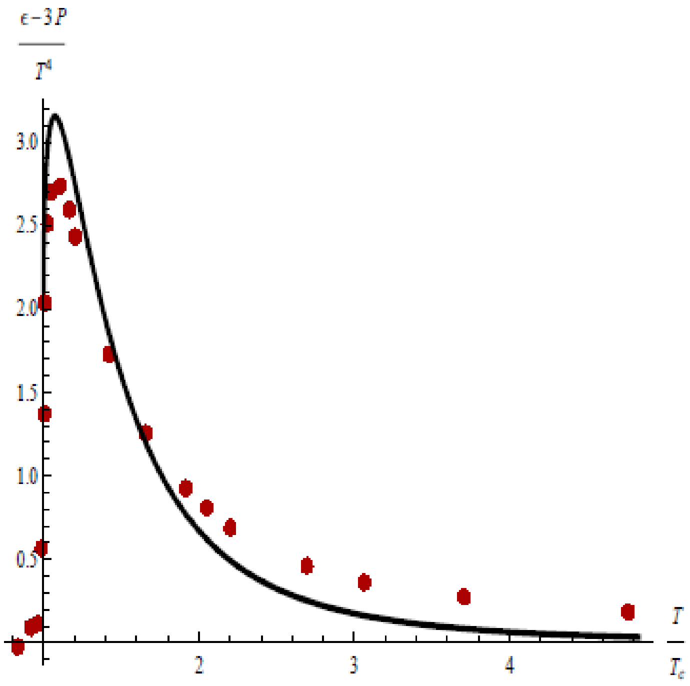
D.N. Li, S. He, M.Huang, Q. S. Yan, arXiv:1103.5389, JHEP2011

# 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

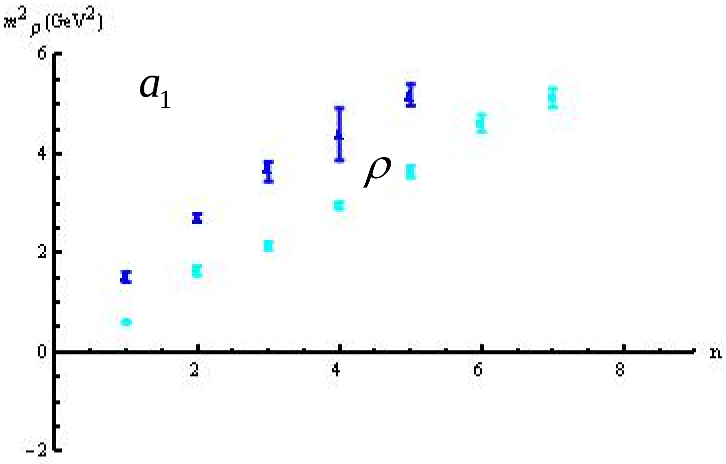
**Chiral symmetry breaking:**

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

Mass split in chiral partner

**Confinement:**

Linear spectra in highly excited states



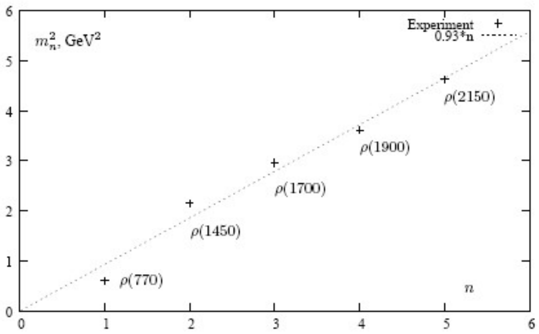

Data from C.Amsler et.al, Phys.Lett.B667(2008)1

# KKSS model

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

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

Chiral symmetry is broken by the expectation value of X

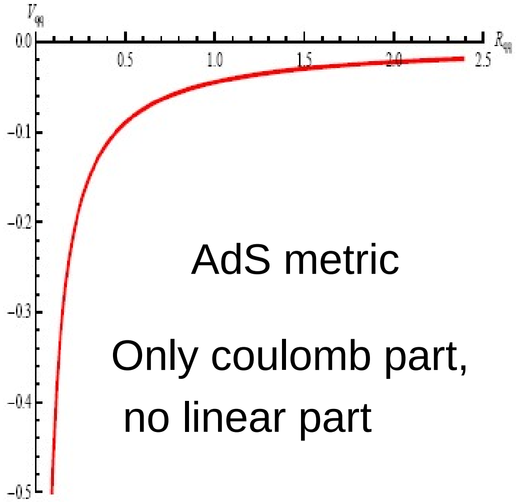



$$X = \frac{\chi}{2} I_{2\times 2}, \quad \chi = m_q z + \sigma z^3 + o(z^4)$$

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

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

Chiral Symmetry breaking




AdS metric

Only coulomb part, no linear part

## A successful holography 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

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

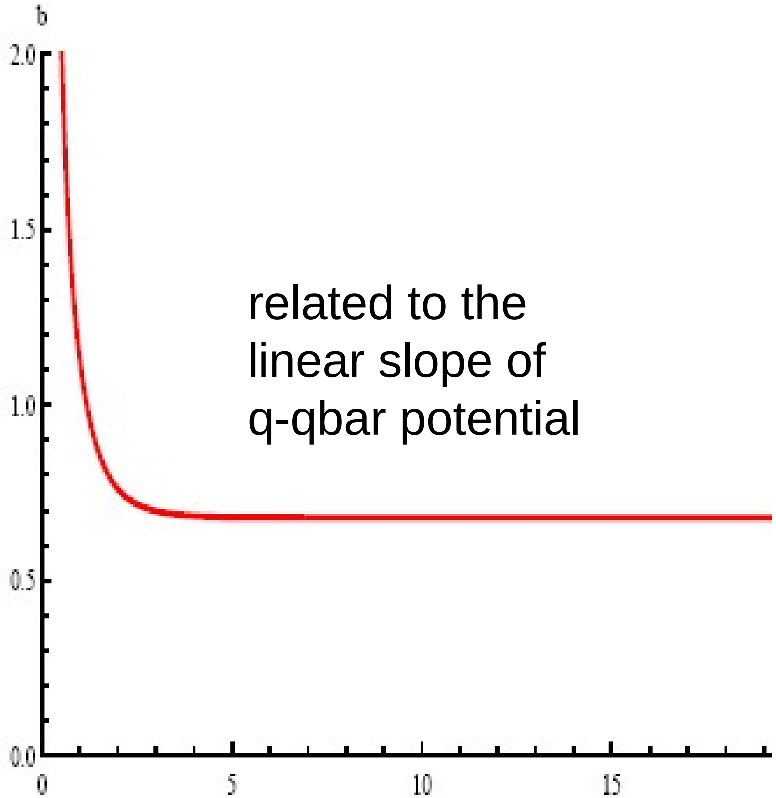
Dilaton profile

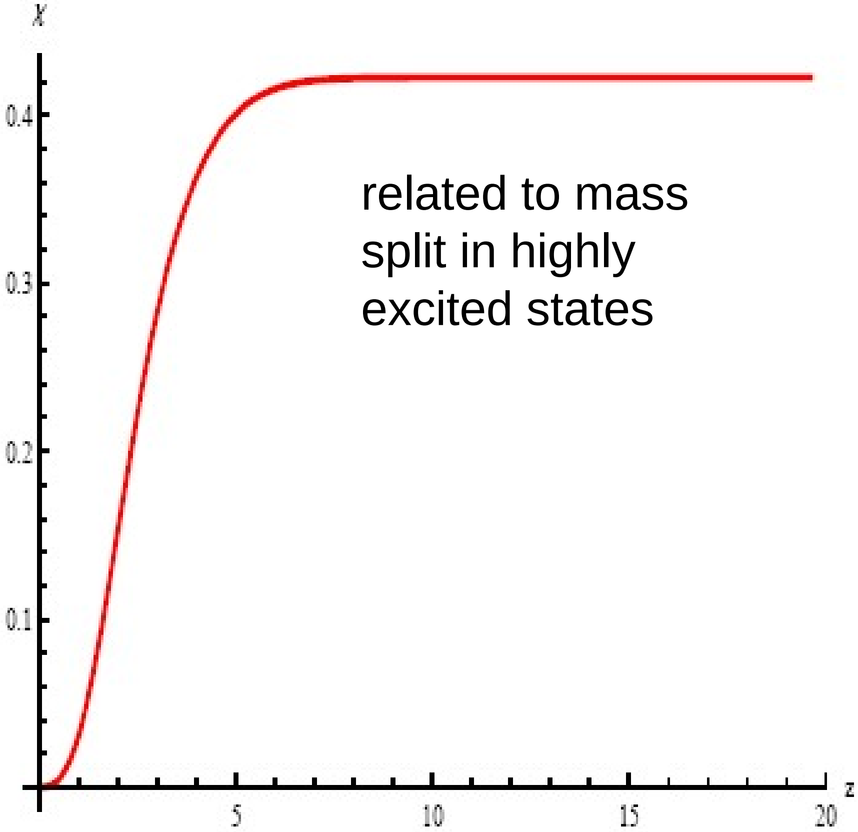
$$\phi = \mu^2 z^2$$

UV behavior of $\chi$

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

# The Background Solution



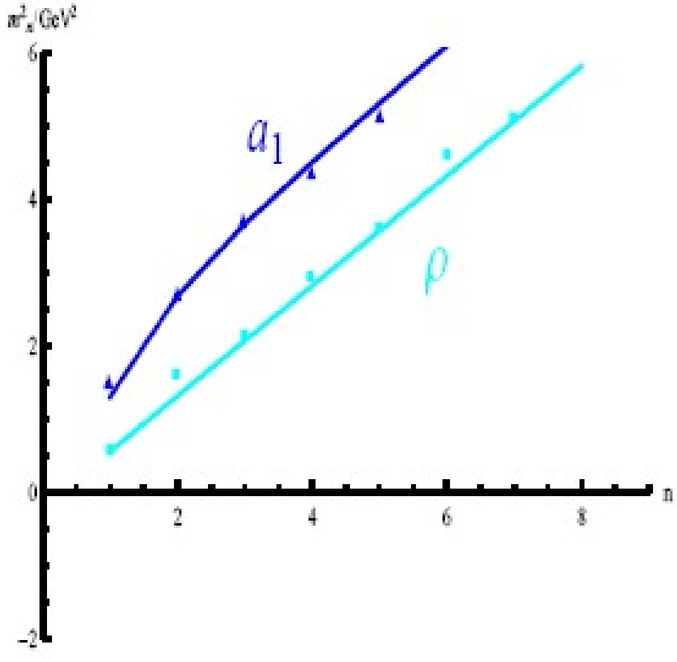




D.Li, M.Huang, and Q.S.Yan, arxiv:1206.2824

# 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

Chiral partner get a mass split




The slope is $4\mu^2$

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

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

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

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

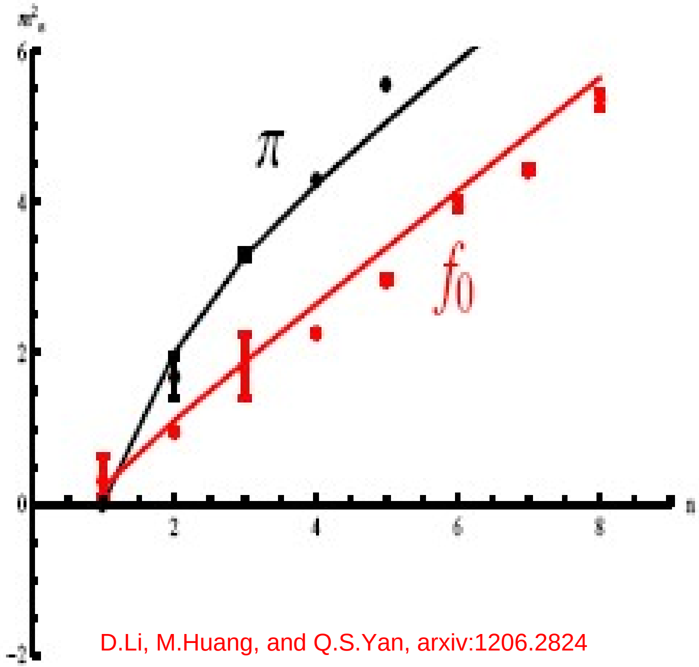
# pi-f0 masses

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

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

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

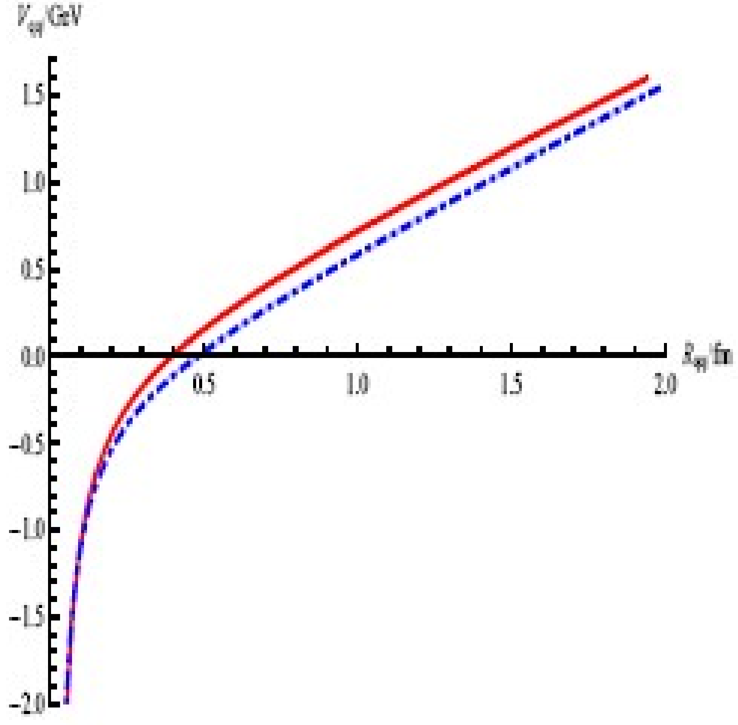
# The quark antiquark potential

The linear potential is produced.

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

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

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




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

Some dimension-2 operatror related to gluon dynamics ?

Need further study

# 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 !