Chiral phase transition from holography

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Content

Recent works on chiral phase transition in DhQCD:

1， Realization of chiral symmetry breaking and restoration in holographic QCD，
Kaddour Chelabi, Zhen Fang, Mei Huang, Danning Li, Yue-Liang Wu
Phys.Rev. D93 (2016) no.10, 101901

2, Chiral Phase Transition in the Soft-Wall Model of AdS/QCD，
Kaddour Chelabi, Zhen Fang, Mei Huang, Danning Li, Yue-Liang Wu
JHEP 1604 (2016) 036

3, Chiral phase transition of QCD with Nf=2+1Nf=2+1 flavors from holography
Danning Li, Mei Huang， arXiv:1610.09814

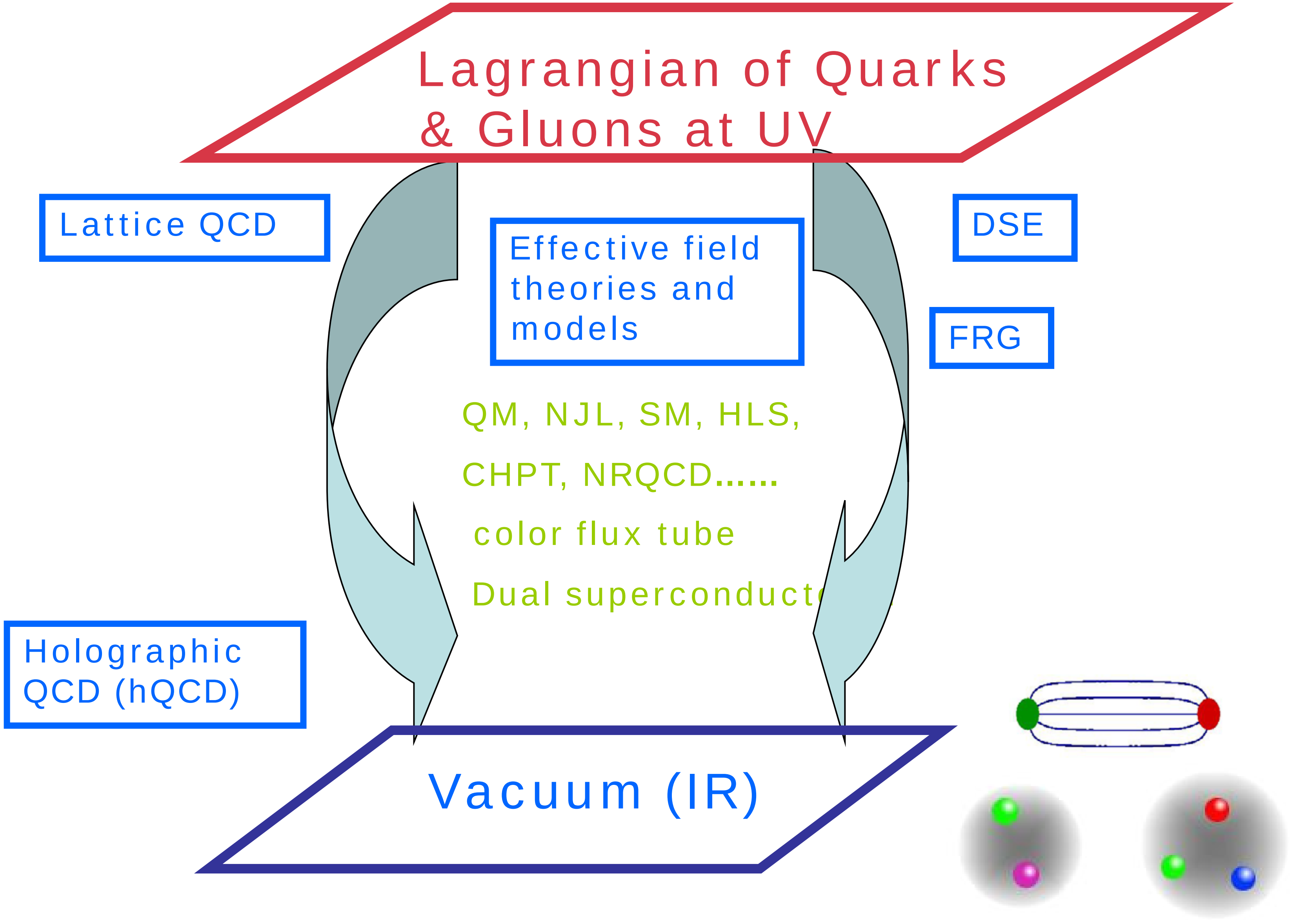
4, Inverse Magnetic Catalysis in the Soft-Wall Model of AdS/QCD，
Danning Li, Mei Huang, Yi Yang, Pei-Hung Yuan
arXiv:1610.04618

Main Collaborator: Danning Li
Jinan Uni., Guangzhou

I. Dynamical hQCD model

----- 5D effective QCD model

Strong QCD


Lagrangian of Quarks
& Gluons at UV
Lattice QCD
Effective field theories and models
DSE
FRG
QM, NJL, SM, HLS,
CHPT, NRQCD……
color flux tube
Dual superconduct
Holographic QCD (hQCD)
Vacuum (IR)

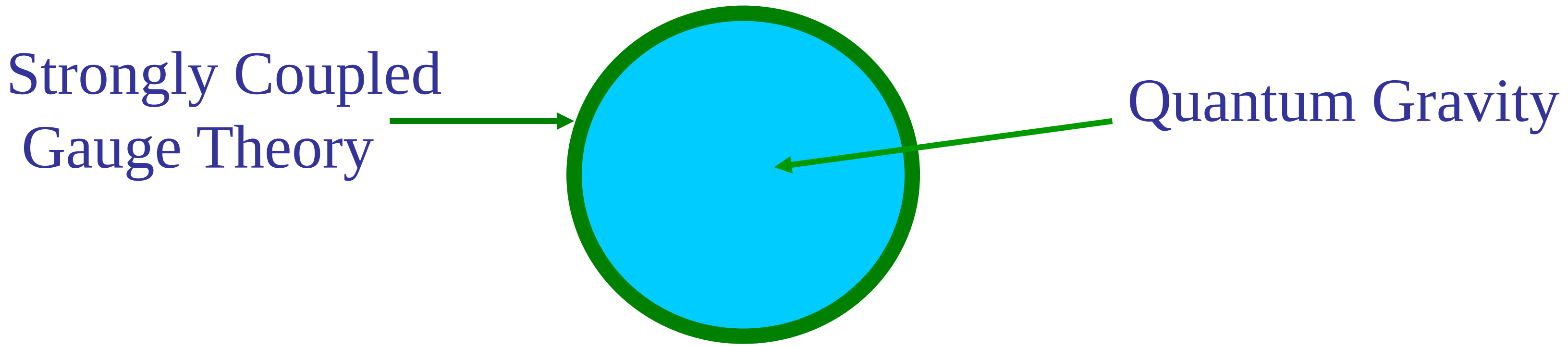
Holographic Duality: Gravity/QFT

AdS/CFT : Original discovery of duality

J. M. Maldacena, Adv. Theor. Math. Phys. **2**, 231 (1998)

Supersymmetry and conformality are required for AdS/CFT.

Holographic Duality: (d+1)-Gravity/ (d)-QFT

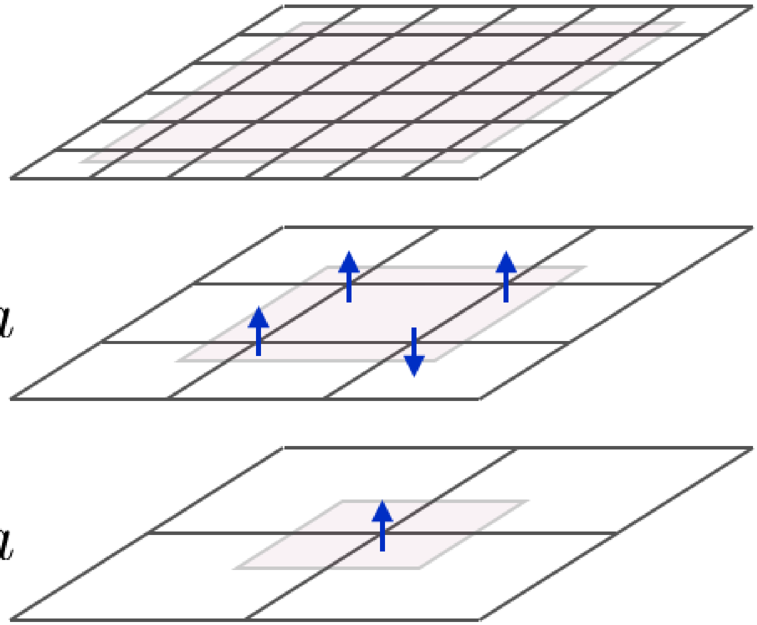


Holographic Duality & RG flow

Coarse graining spins on a lattice: Kadanoff and Wilson

$$H = \sum_{x,i} J_i(x)\mathcal{O}^i(x)$$

J(x): coupling constant or source for the operator



a

$$H = \sum_i J_i(x,a)\,\mathcal{O}^i(x)$$

$2a$

$$H = \sum_i J_i(x,2a)\,\mathcal{O}^i(x)$$

$4a$

$$H = \sum_i J_i(x,4a)\,\mathcal{O}^i(x)$$

$$u\frac{\partial}{\partial u}J_i(x,u) = \beta_i(J_j(x,u),u)$$

arXiv:1205.5180

Holographic Duality & RG flow

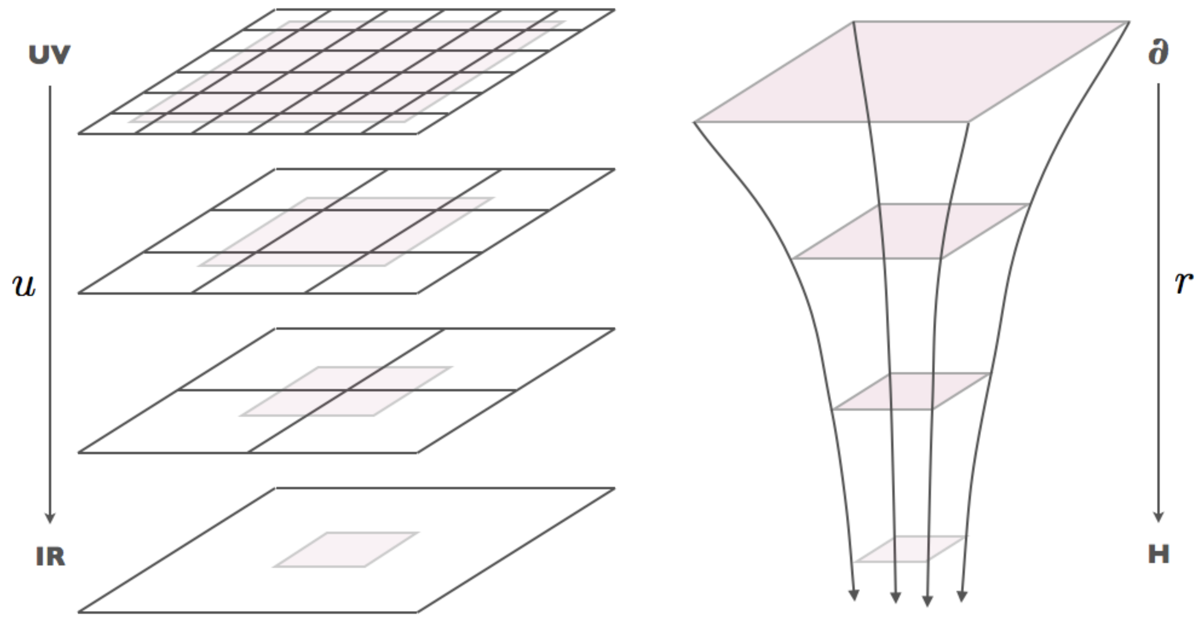
QFT on lattice   equivalent to   GR problem from Gravity

RG scale -> an extra spatial dimension

Coupling constant -> dynamical filed

arXiv:1205.5180

$$J_i|_{UV} \quad = \quad \Phi_i|_\partial$$



The extra dimension plays the role of energy scale in QFT, with motion along the extra dimension representing a change of scale, or renormalization group (RG) flow.

A systematic framework: Graviton-dilaton system

$$S_G = \frac{1}{16\pi G_5} \int d^5x \sqrt{g_s} e^{-2\Phi} \left(R_s + 4\partial_M \Phi \partial^M \Phi - V_G^s(\Phi) \right)$$

N=4 Super YM

conformal

AdS$_5$

$$ds^2 = \frac{L^2}{z^2} \left(dt^2 + d\vec{x}^2 + dz^2 \right)$$

$$V_E(\phi) = -\frac{12}{L^2}$$

QCD

nonconformal

deformed AdS$_5$

$$ds^2 = \frac{h(z) L^2}{z^2} \left(dt^2 + d\vec{x}^2 + dz^2 \right)$$

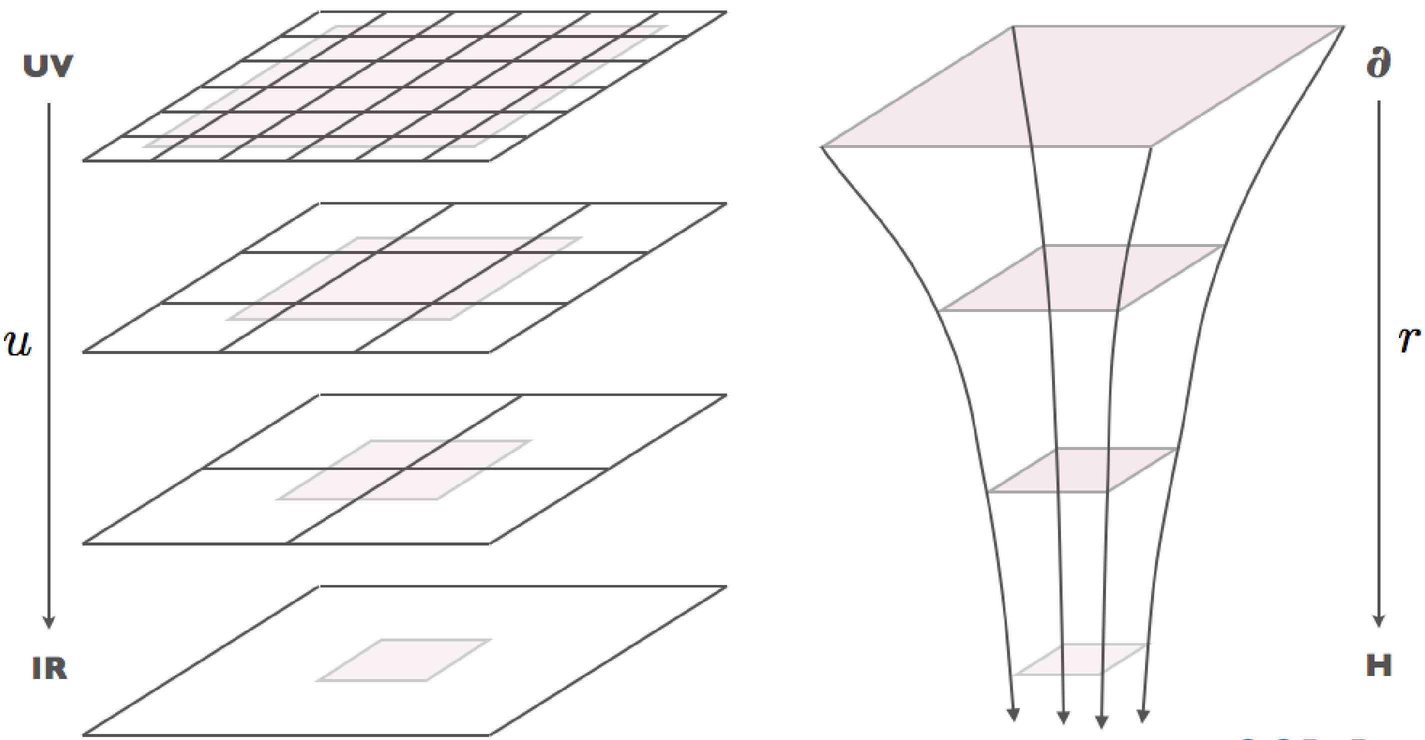
Dilaton field breaks conformal symmetry

Input: QCD dynamics at IR

Solve: Metric structure, dilaton potential

Dynamical hQCD & RG

$$J_i|_{UV} \quad = \quad \Phi_i|_{\partial}$$



A AdS$_5$

From UV to IR

QCD Dynamics at IR

deformed AdS$_5$

Progresses made in 2012-2015:

Hadron spectra
chiral symmetry breaking
& linear confinement

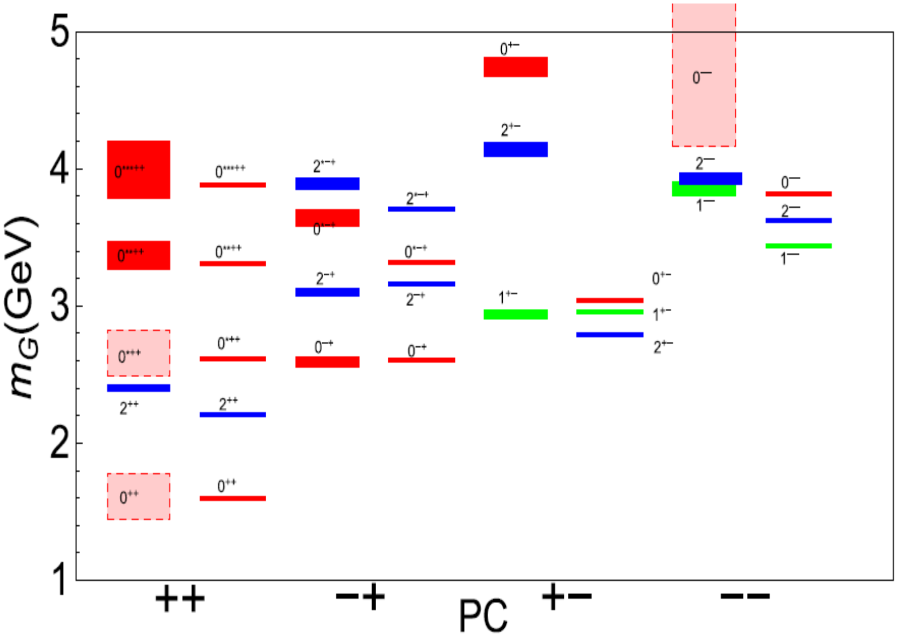
Phase transitions (deconfinement)

Equation of state

Transport properties

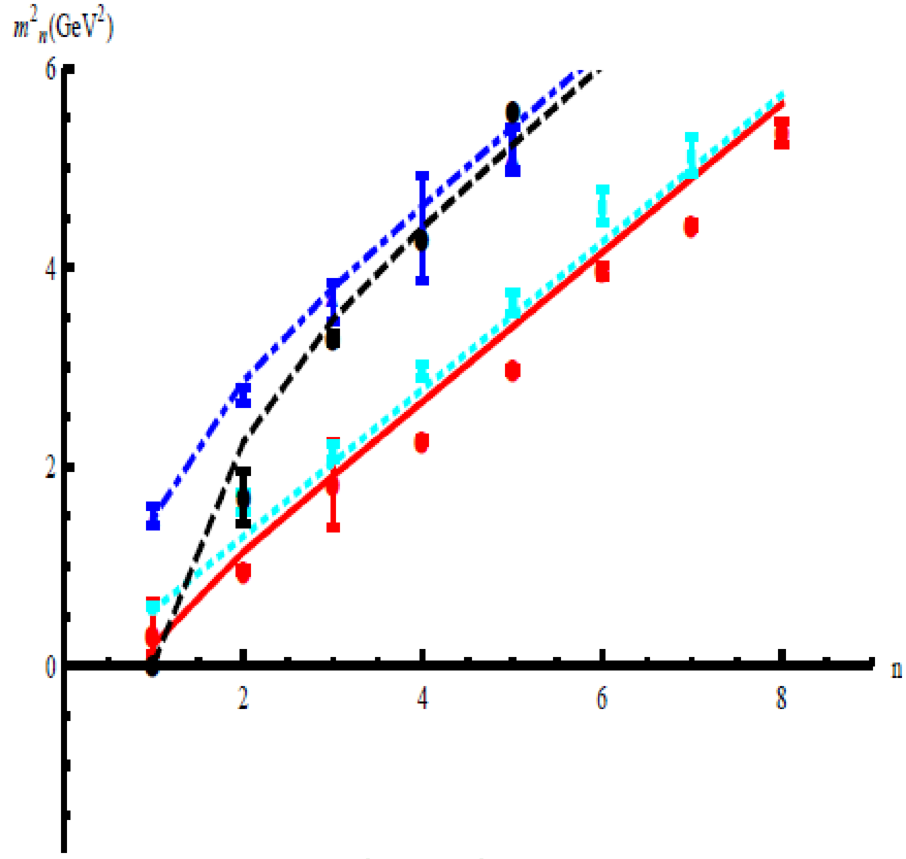
in one systematic framework

Glueball spectra



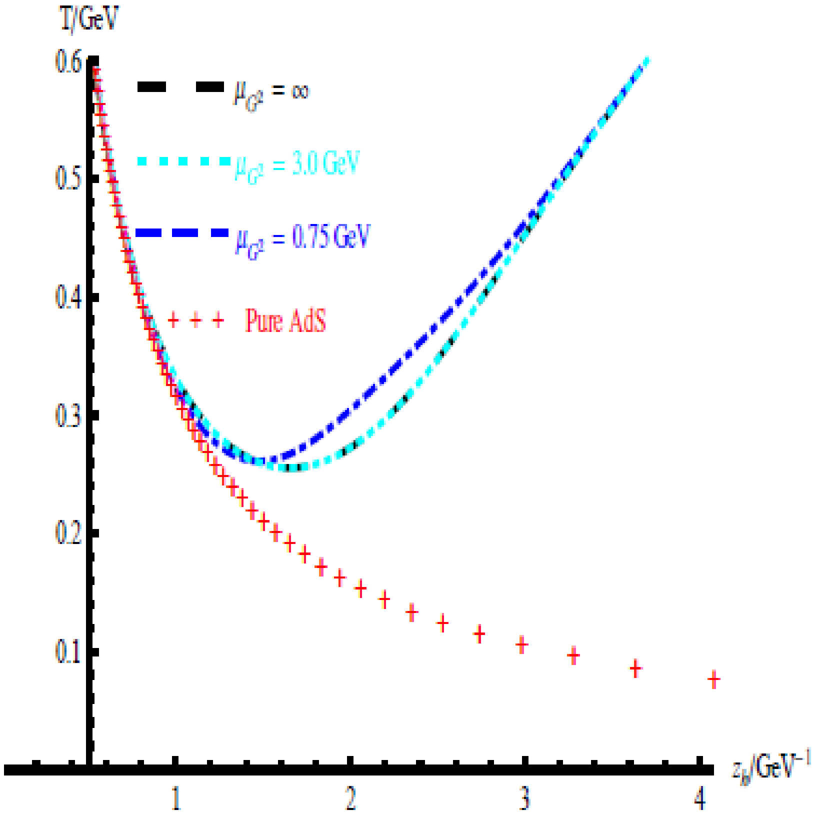
Yidian Chen, M.H.,
arXiv: 1511.07018,CPC2017

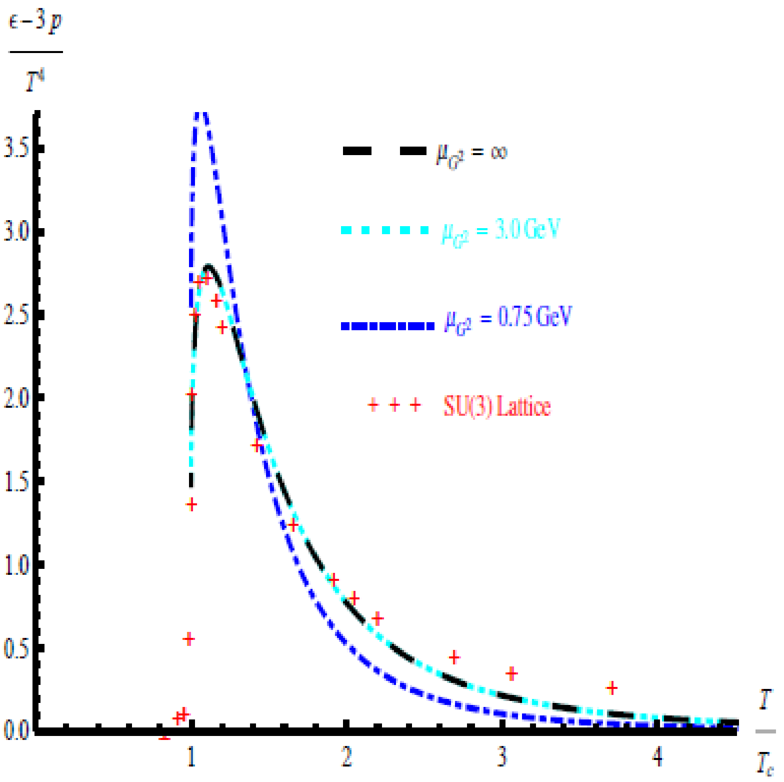
Hadron spectra



Danning Li, M.H.,
arXiv:1303.6929,JHEP2016

Equation of state

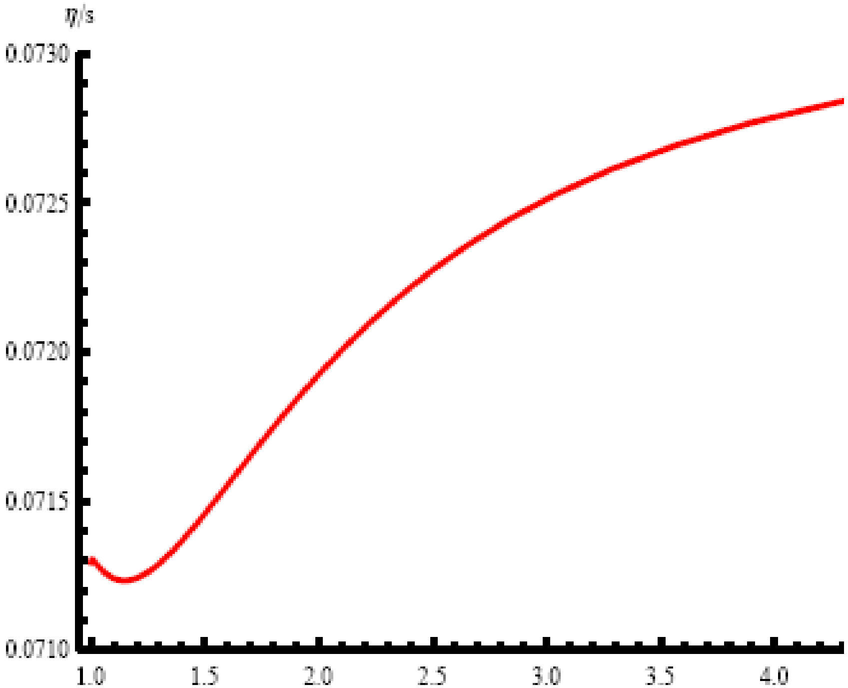


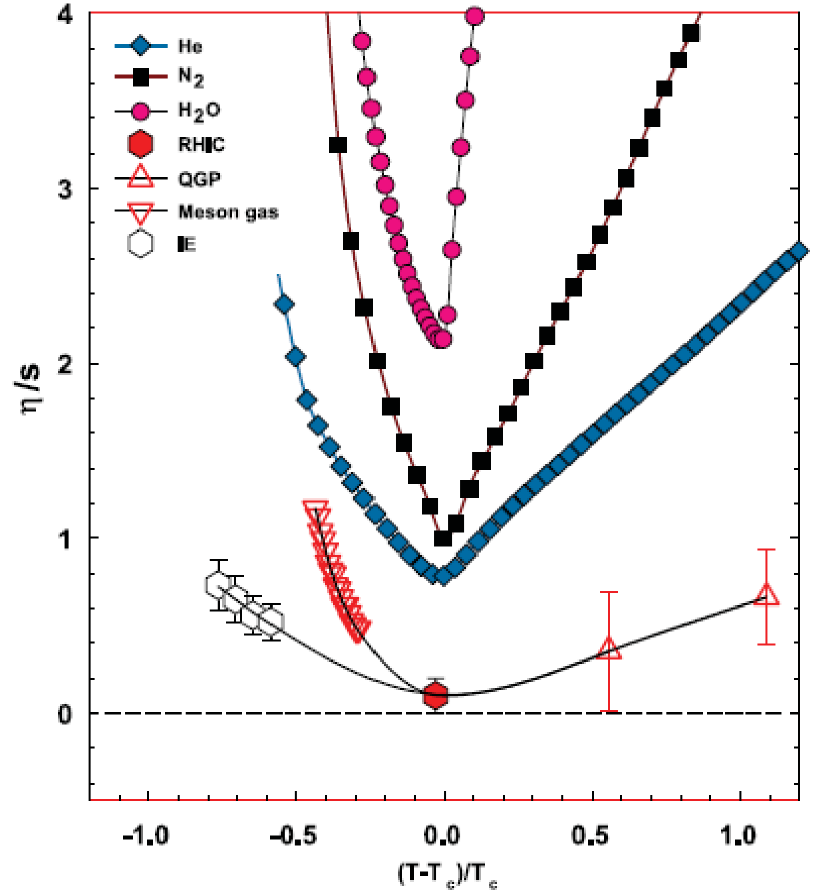


Danning Li, Jinfeng Liao, M.H. arXiv:1401.2035, PRD2014

Transport properties

Shear viscosity

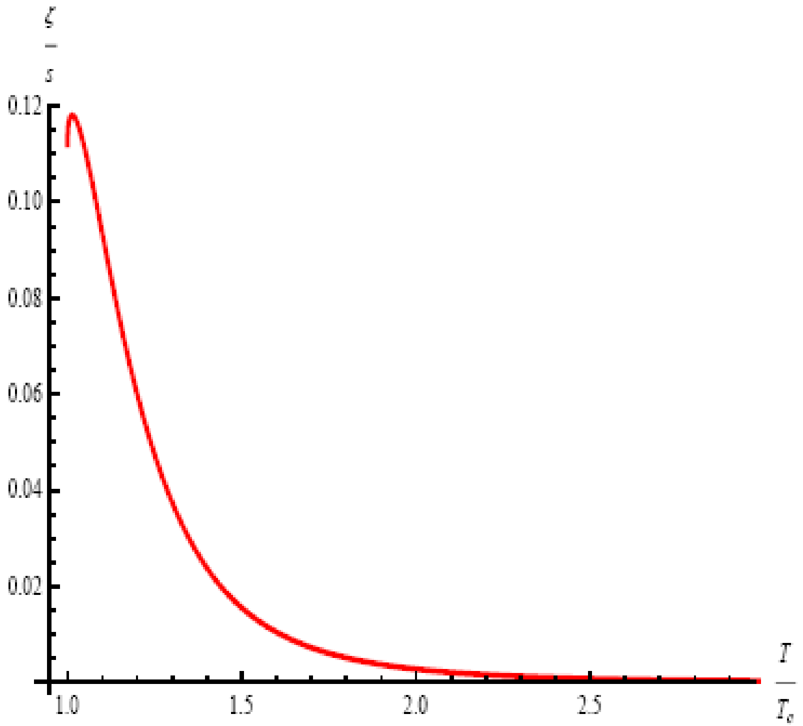


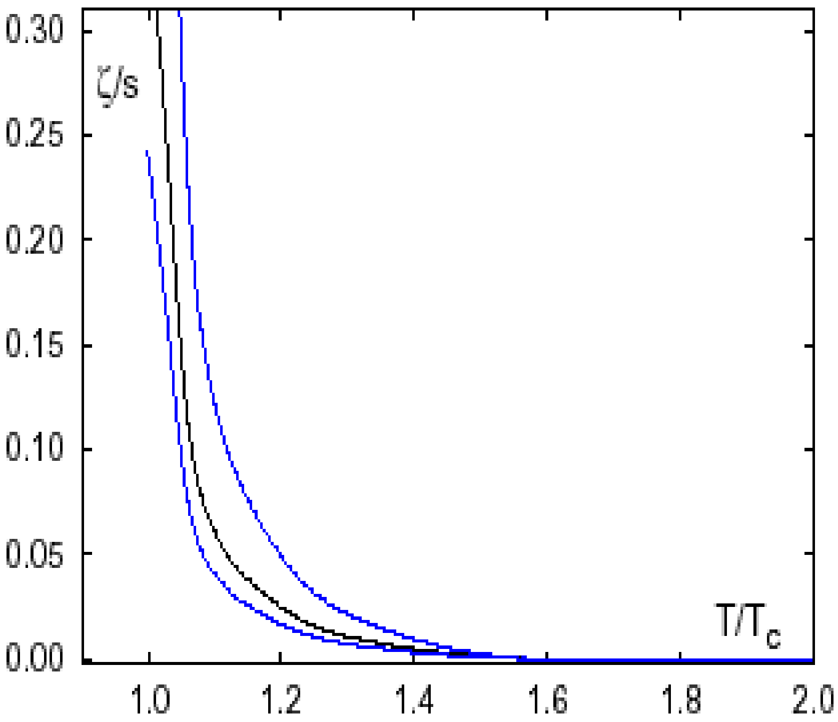


Danning Li, Song He, M.H. JHEP2015

Lacey et al., PRL 98:092301,2007

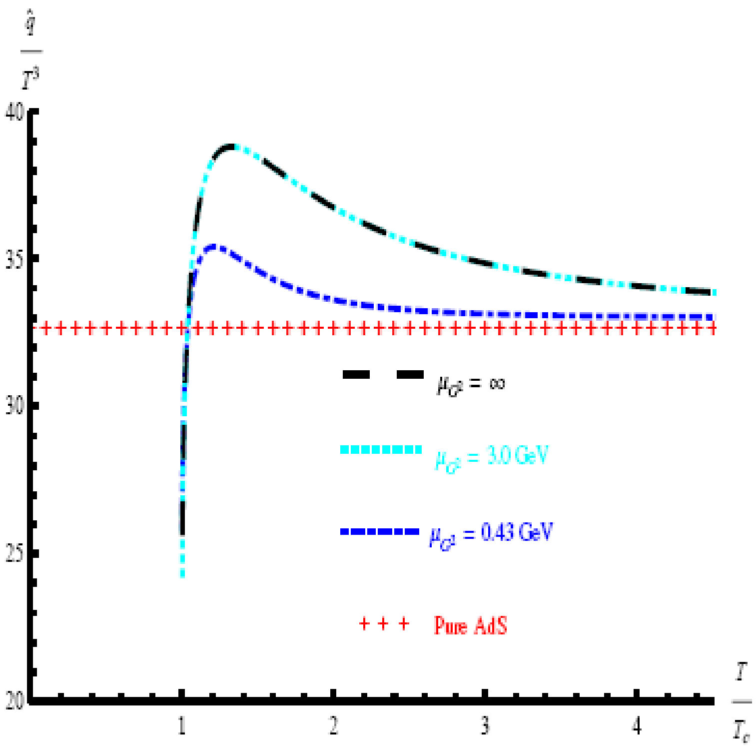
Bulk viscosity

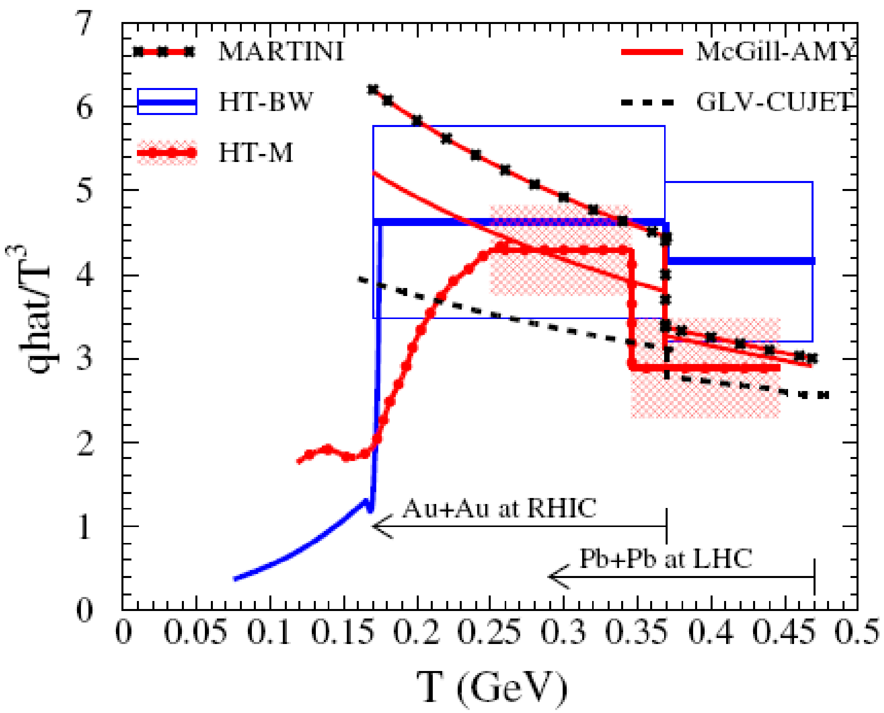




Danning Li, Song He, M.H. JHEP2015 Dmitri Kharzeev, Kirill Tuchin arXiv:0705.4280,

Jet quenching





Danning Li, Jinfeng Liao, M.H.
arXiv:1401.2035, PRD2014

[Jet Collaboration]
arXiv:1312.5003

II. Realization of chiral symmetry breaking & restoration

First time in holographic QCD model

K. Chelabi, Z.Fang, M.Huang, D.N.Li, Y.L.Wu,
arXiv:1511.02721,
arXiv:1512.06493

Only focus on the scalar sector:

$$SU(N_f)_L \times SU(N_f)_R$$

$$S = -\int d^5x\sqrt{-g}e^{-\Phi}Tr(D_m X^+ D^m X + V_X(|X|)).$$

$$ds^2 = e^{2A_s(z)}(-f(z)dt^2 + \frac{1}{f(z)}dz^2 + dx_i dx^i),$$

$$A_s(z) \;=\; -\log(z),$$

$$f(z) \;=\; 1 - \frac{z^4}{z_h^4}.$$

$$S_\chi = -\int d^5x\sqrt{-g}e^{-\Phi}\left(\frac{1}{2}g^{zz}\chi'^2 + V(\chi)\right),$$

$$X_0 = \frac{\chi(z)}{\sqrt{2N_f}}I_{N_f}$$

Profile of the scalar potential

$$V(\chi) \equiv Tr(V_X(|X|)) = -\frac{3}{2}\chi^2 + v_3\chi^3 + v_4\chi^4.$$

Only for three-flavor scalar

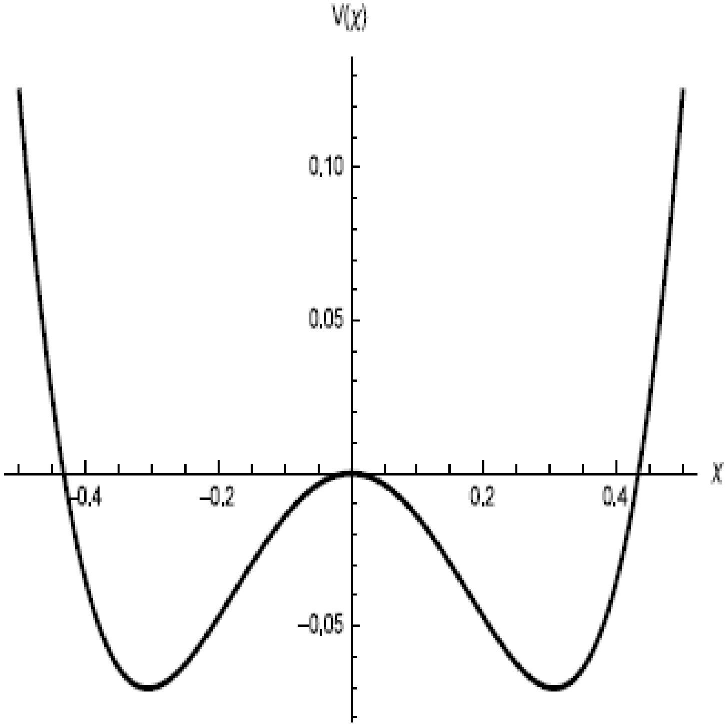
Profile of the dilaton field

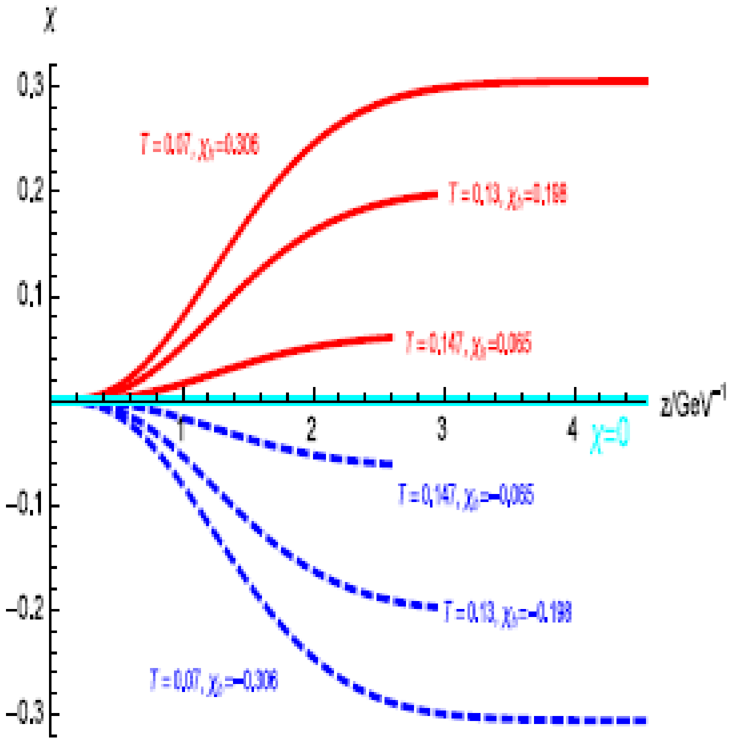
$$\Phi(z) = -\mu_1 z^2 + (\mu_1+\mu_0)z^2\tanh(\mu_2 z^2),$$

Nagative at UV, same as Brodsky and Zuo

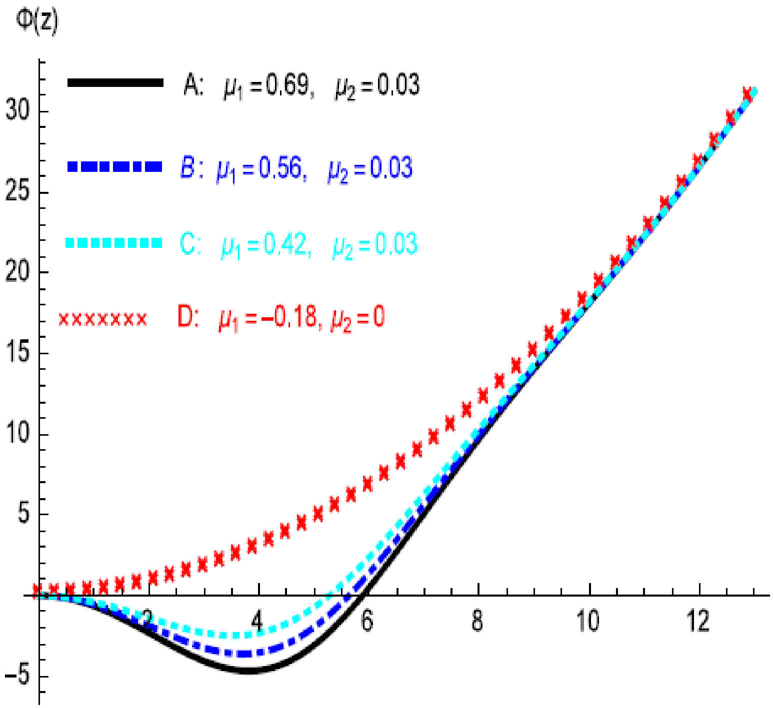
F. Zuo, Phys. Rev. D **82**, 086011 (2010)
T. Gutsche, V. E. Lyubovitskij, I. Schmidt and A. Vega, Phys. Rev. D **85**, 076003 (2012)

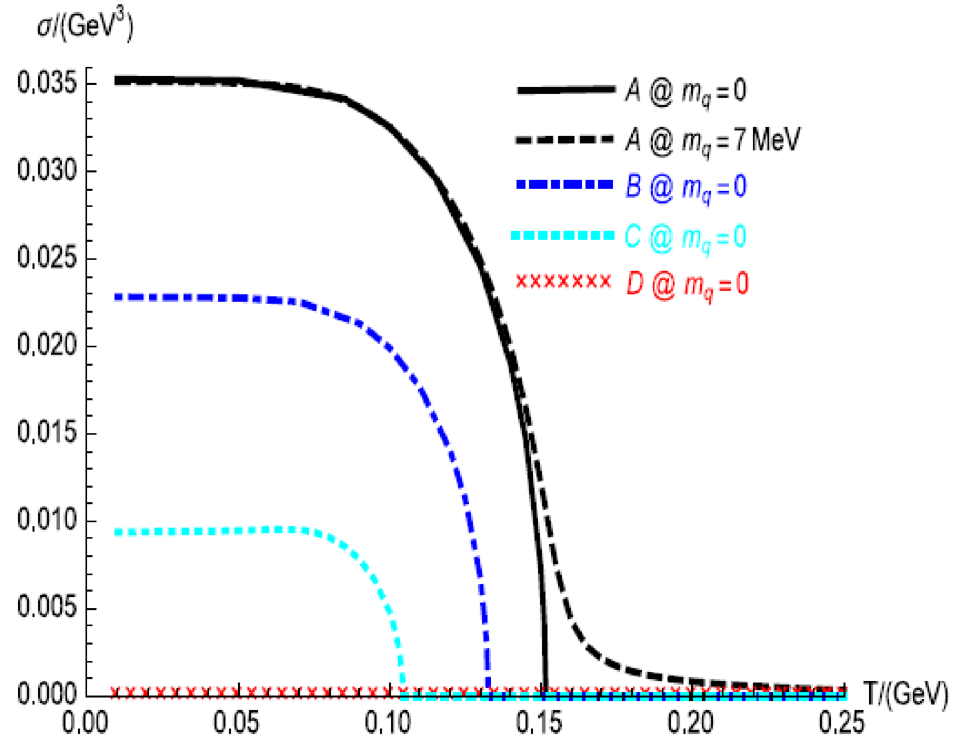
Profile of the scalar potential determines the possible solution of the chiral condensate





Profile of the dilaton field represents the gluodynamics, and it determines the real solution of the chiral condensate

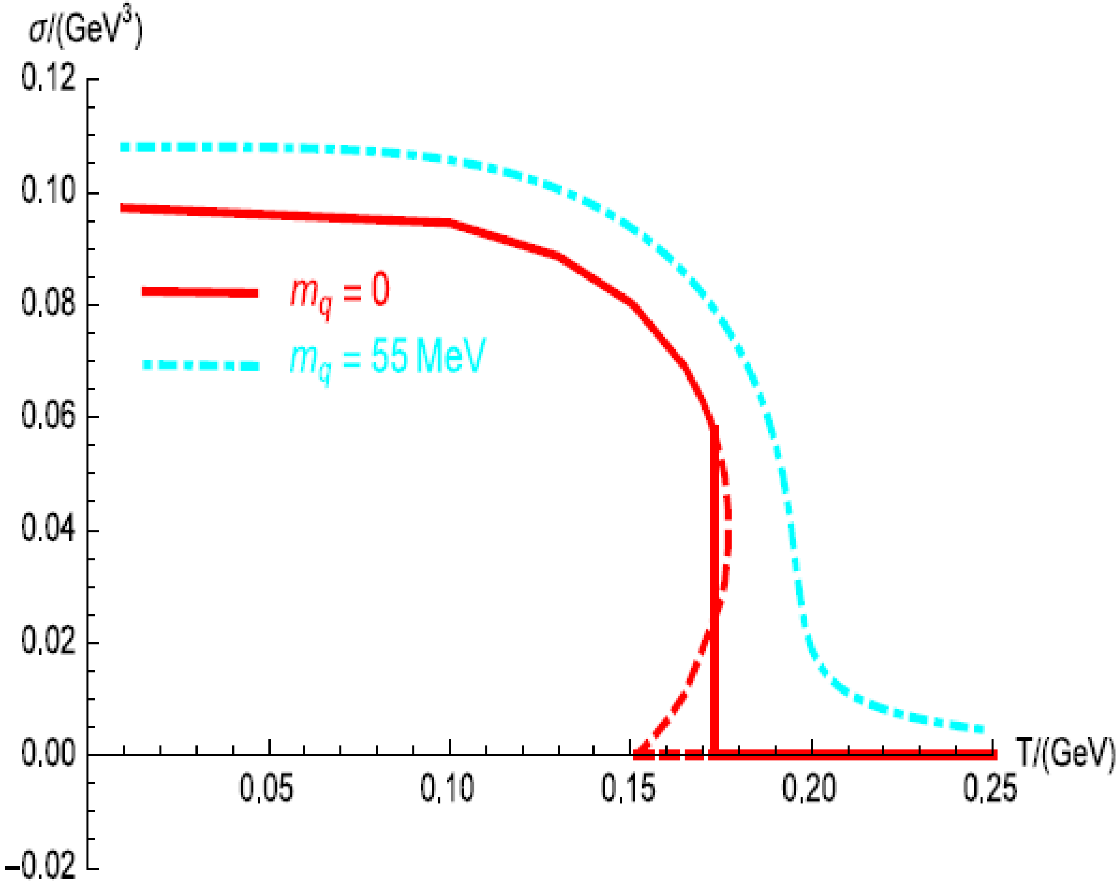




Two-flavor case:

chiral limit, 2nd order phase transition

nonzero current quark mass, cross-over



Three-flavor case:

chiral limit, 1st order phase transition

finite current quark mass, cross-over

III. Colombia Plot

Danning Li, Mei Huang, arXiv:1610.09814

Extension to Nf=2+1

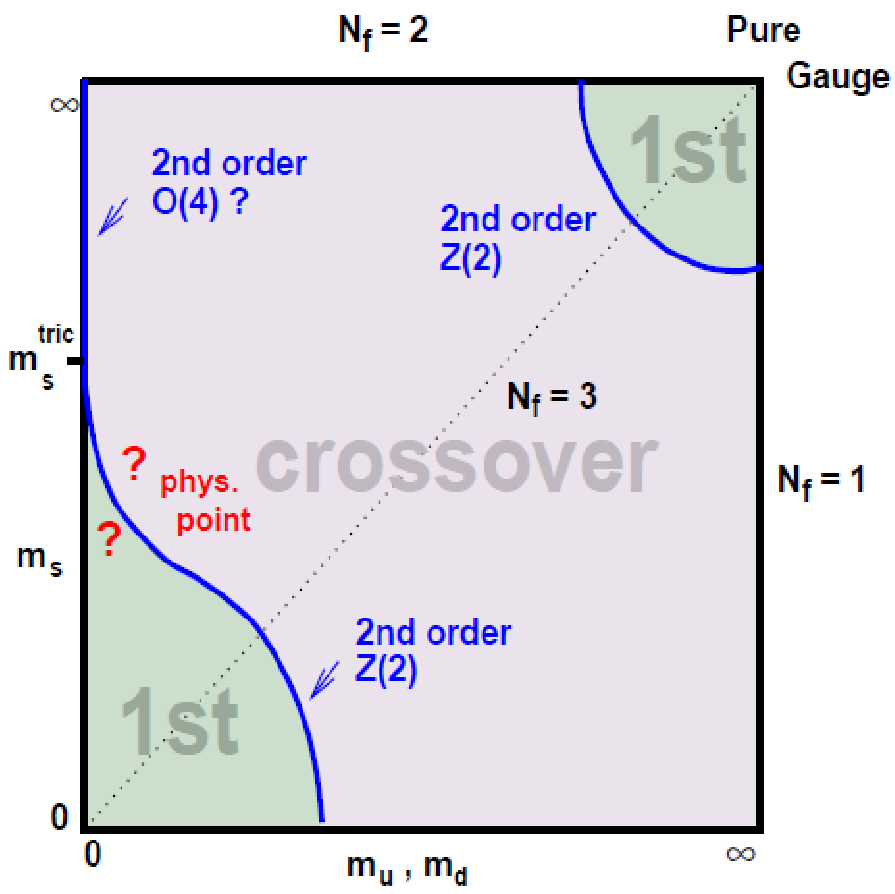
Danning Li, M.Huang, arXiv:1610.09814

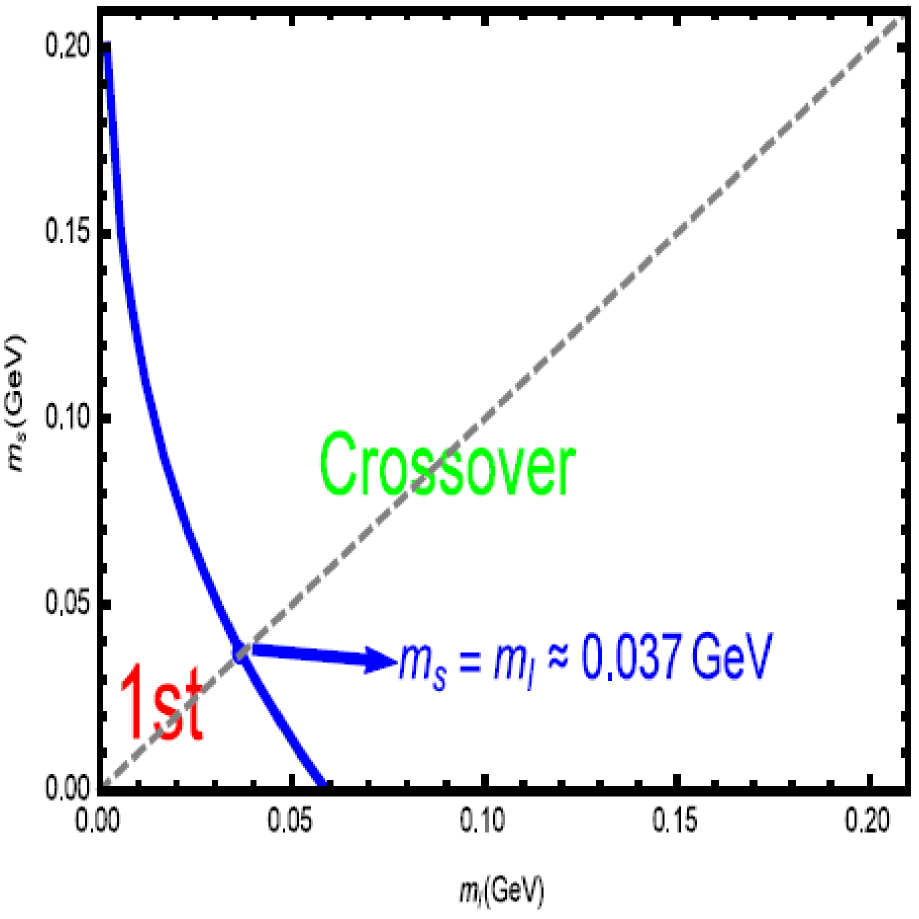
$$S = -\int d^5x\sqrt{-g}e^{-\Phi}Tr(D_m X^+ D^m X + V_X(X) + \frac{1}{4g_5^2}(F_L^2 + F_R^2)),$$

$$m_l \equiv m_u = m_d \neq m_s$$

$$X = \begin{pmatrix} \frac{\chi_l(z)}{\sqrt{2}} & 0 & 0 \\ 0 & \frac{\chi_l(z)}{\sqrt{2}} & 0 \\ 0 & 0 & \frac{\chi_s(z)}{\sqrt{2}} \end{pmatrix},$$

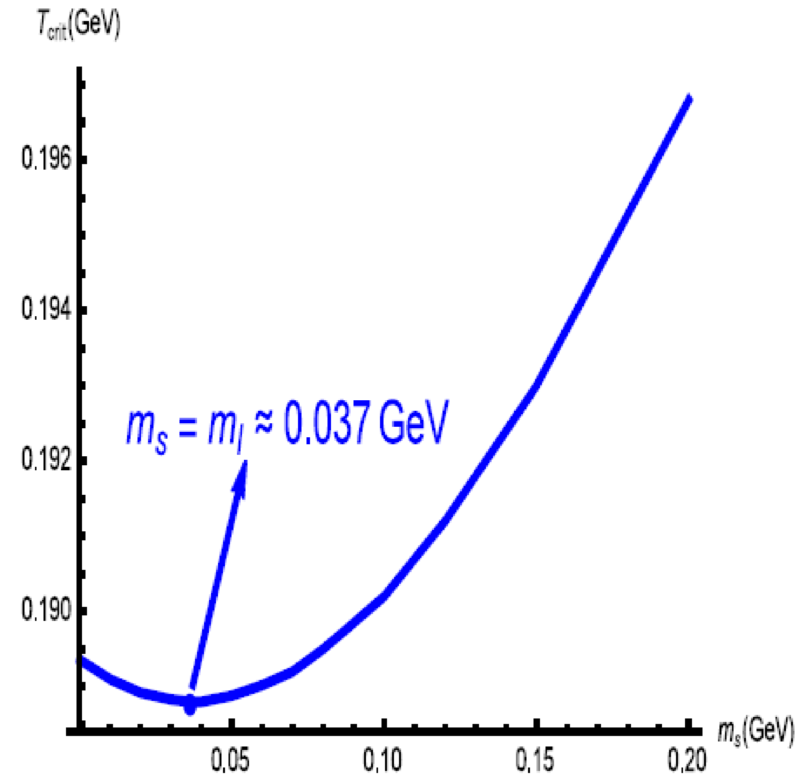
Colombia Plot

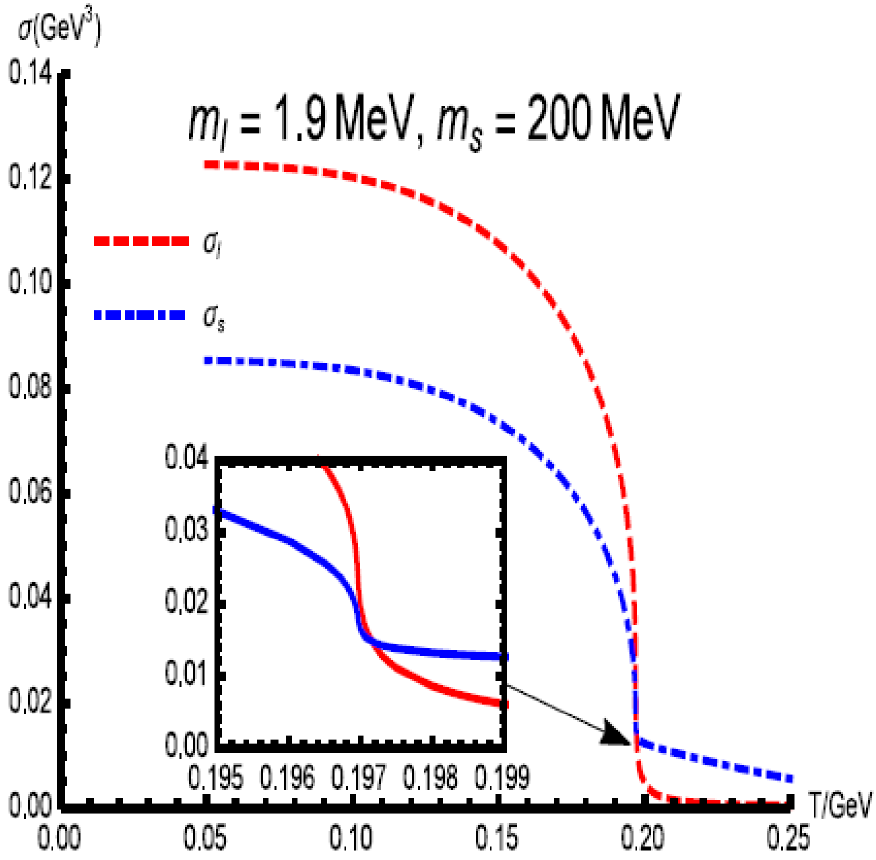




Danning Li, M.Huang, arXiv:1610.09814

Interesting observation:



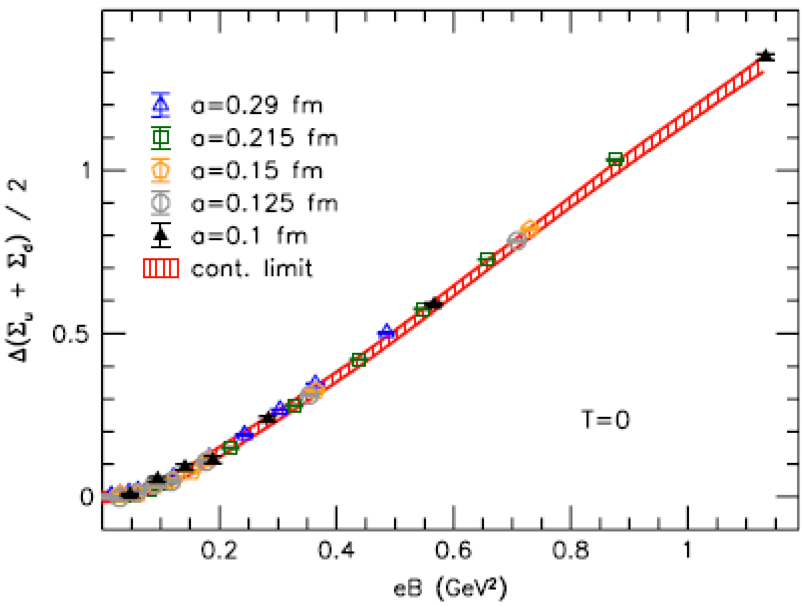


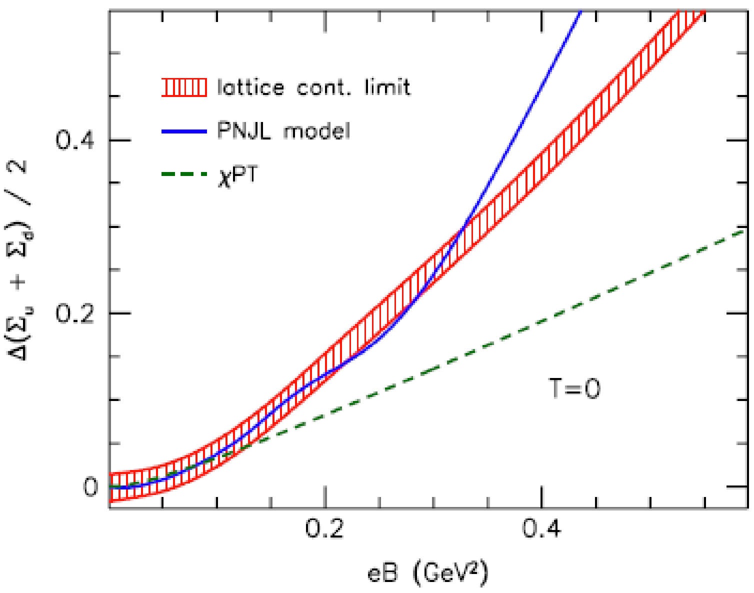
No flavor separation phase transition!

IV. Inverse magnetic catalysis from holography

Magnetic catalysis at zero temperature

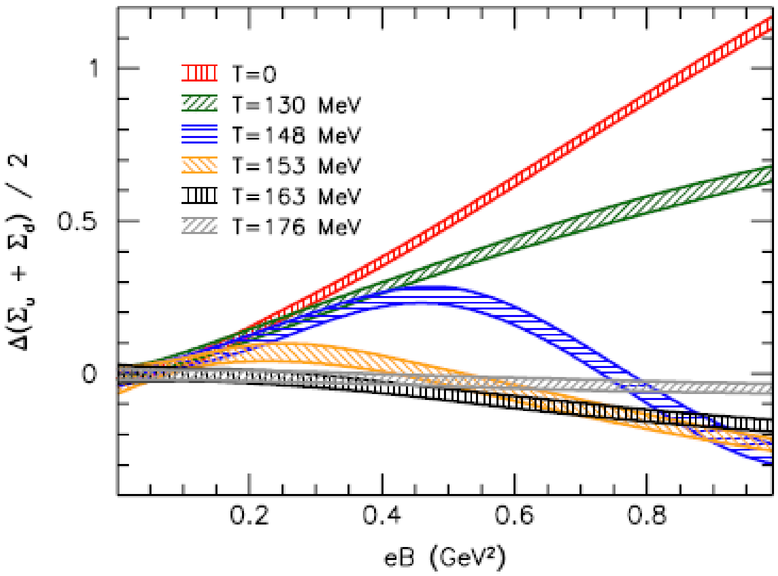
Bali et al. arXiv:1206.4205 [hep-lat]

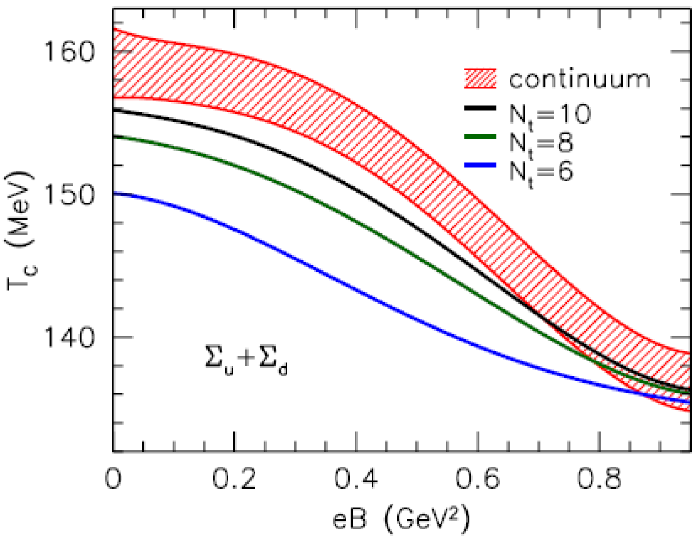




Inverse magnetic catalysis at nonzero temperature

Bali et al. arXiv:1206.4205 [hep-lat]





Surprise ! Puzzle!

In our current understanding of the chiral phase transition, some important information is missing, which might be revealed by magnetic fields!

How to understand inverse magnetic catalysis ?

1) Magnetic inhibition K. Fukushima, Y. Hidaka, PRL 110, 031601 (2013)

Contribution from neutral pions

2) Contribution from sea quarks

Bruckmann et.al. arXiv:1303.3972

3) Polyakov holomoly Nowak et.al. arXiv:1304.6020

4) Running coupling Ferreira et.al. arXiv:1404.5577

5) Chirality imbalance

Sphaleron transition

Jingyi Chao, Pengcheng Chu, MH, arXiv:1305.1100, PRD88(2013)

Instanton-anti-instanton pairing condensate

Lang Yu, Hao Liu, MH, arXiv:1404.6969, PRD90(2014)
Lang Yu, Jos Doorsselaere, MH, arXiv:1411.7752

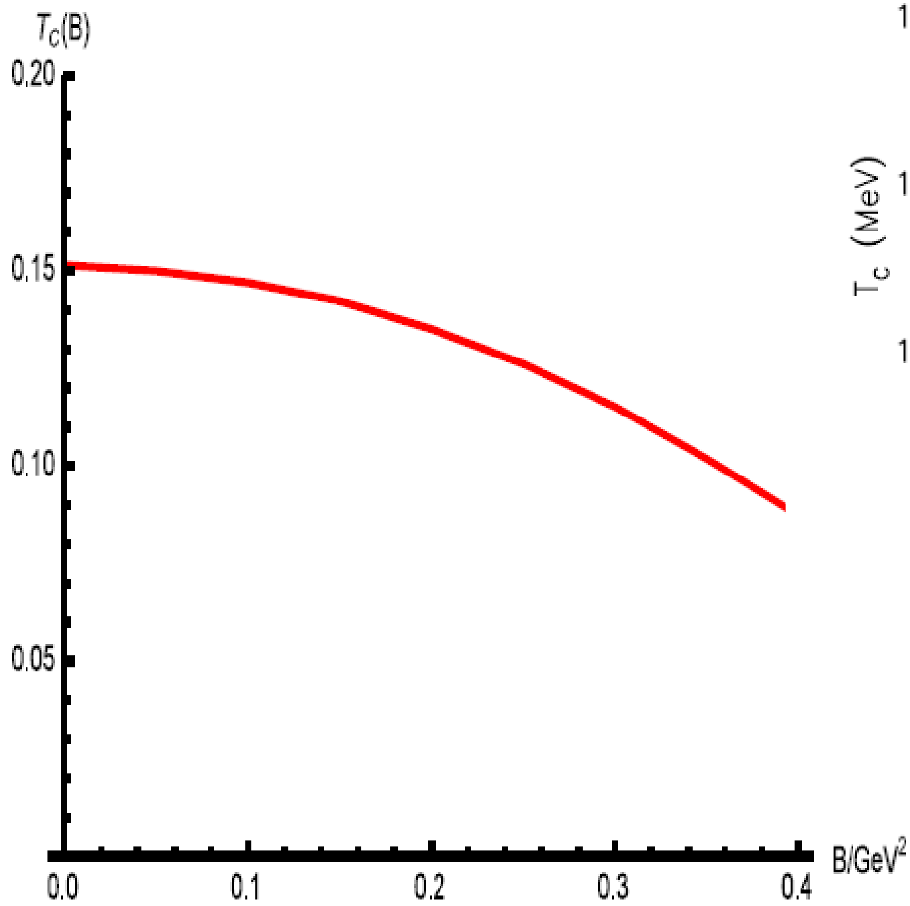
IMC from holography

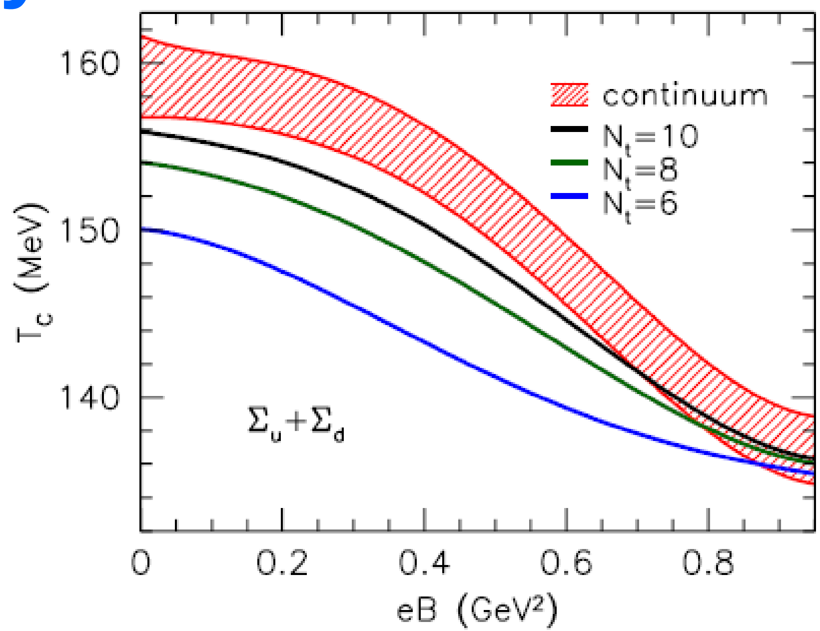
Danning Li, Mei Huang, Yi Yang, Pei-Hung Yuan
arXiv:1610.04618

$$S_B = \frac{1}{16\pi G_5}\int d^5x\sqrt{-g}\left(R - F^{MN}F_{MN} + \frac{12}{L^2}\right),$$

$$S = -\int d^5x\sqrt{-g}e^{-\Phi}Tr(D_m X^+ D^m X + V_X + \frac{1}{4g_5^2}(F_L^2 + F_R^2)),$$

IMC from holography





in agreement with lattice result

Warning: weak magnetic field expansion has been used

V. Conclusion and Outlook

In the DhQCD model, we have achieved:

1, QCD vacuum properties

glueball spectra, light-flavor meson spectra,

chiral symmetry breaking and linear confinement

2, QCD phase transitions

deconfinement phase transition(HP) & chiral phase transition(Landau)

3, Equation of state for QCD matter agree with lattice result.

4, Temperature dependent transport properties reflect phase transitions of QCD.

5D effective QCD model is more powerful than 4D effective QCD model!

To-do-list in the future

1, Heavy flavor physics (struggled for a long time, but now in progress)

SU(2)->SU(3)->SU(4)

2, Check CEP

Go to high density (add chemical potential)

3, Relationship between chiral and deconfinement phase transitions

4, Equation of state and transport properties for 1^{st} order phase transition (inhomogeneous phase)

5, CME and CVE

6, ……

Thanks for your attention!