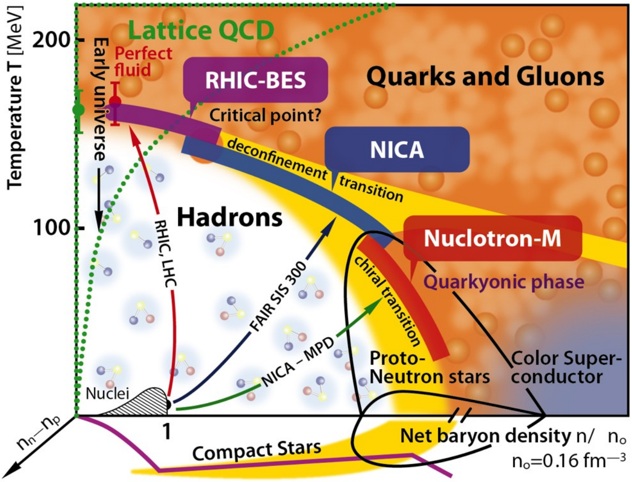
О критической точке и Редже-спектрах мезонов в голографических моделях КГП для легких кварков

К.А. Ранну

РУДН

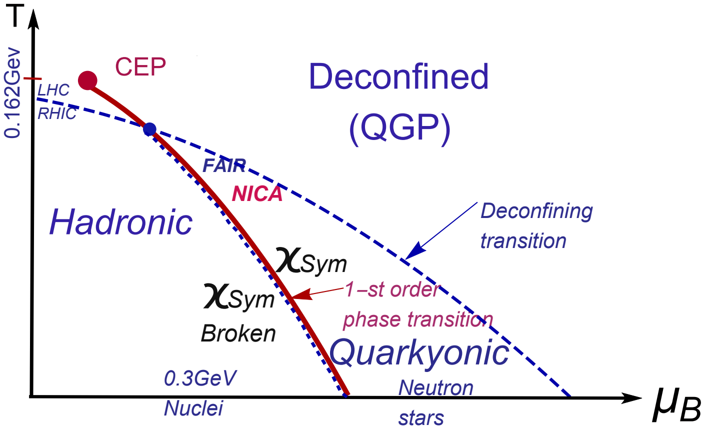
Сессия-конференция «Физика фундаментальных взаимодействий», посвященная 70-летию со дня рождения академика РАН Валерия Анатольевича Рубакова

Studies of QCD phase diagram is the main goal of new facilities



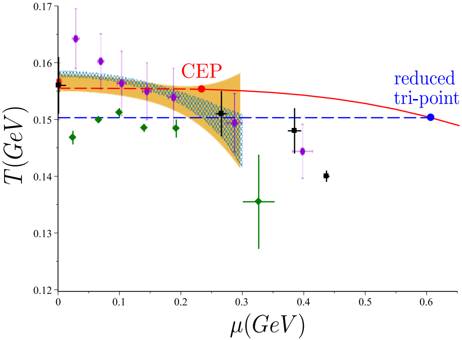
From: https://nica.jinr.ru/physics.php

Holographic QCD phase diagram



In fact for light quarks

Conclusive QCD phase diagram



blue – deconfinement transition
red – χSB transition

yellow zone – HotQC
PLB 795 (2019) 15-21, Quark Matter 2019
blue-net zone – Wuppertal-Budapest
PRL 125 (2020) 052001

STAR, ALICE chemical freeze-out parameters:
black squares *PRL 111 (2013) 082302*
green diamonds *PLB 738 (2014) 305-310*
purple circles *PRC 96 (2017) 4, 044904*
red square *Nature 561 (2018) 7723, 321-330*

$T_d(\mu) \simeq 0.1503$ $\qquad$ $T_\chi(\mu) \simeq 0.1555$ $\qquad$ *PLB 832 (2022) 137212*

$(\mu_t, T_t) \simeq (0.607, 0.150)$ $\qquad$ $(\mu_c, T_c) \simeq (0.234, 0.155)$

Holographic model of an anisotropic plasma in a magnetic field at a nonzero chemical potential

I.Aref'eva, KR'18; IA, KR, P.Slepov'21

$$S = \int d^5x \sqrt{-g}\left[R - \frac{f_0(\phi)}{4} F_{(0)}^2 - \frac{f_1(\phi)}{4} F_{(1)}^2 - \frac{f_B(\phi)}{4} F_{(B)}^2 - \frac{1}{2}\partial_M\phi\partial^M\phi - V(\phi)\right]$$

$$ds^2 = \frac{L^2}{z^2}\,\mathfrak{b}(z)\left[-g(z)\,dt^2 + dx^2 + \left(\frac{z}{L}\right)^{2-\frac{2}{\nu}} dy_1^2 + e^{c_B z^2}\left(\frac{z}{L}\right)^{2-\frac{2}{\nu}} dy_2^2 + \frac{dz^2}{g(z)}\right]$$

$$A_{(1)\mu} = A_t(z)\delta_\mu^0 \qquad A_t(0) = \mu \qquad F_{(1)} = dy^1 \wedge dy^2 \qquad F_{(B)} = dx \wedge dy^1$$

$\mathfrak{b}(z) = e^{2\mathcal{A}(z)}$ $\Leftrightarrow$ quarks mass

"Bottom-up approach"

Heavy quarks (b, t)

$\mathcal{A}(z) = -\, cz^2/4$ — *Andreev, Zakharov'06*

$\mathcal{A}(z) = -\, cz^2/4 + p(c_B)z^4$ — *IA, Hajilou, Rannu, Slepov' 23*

Light quarks (d, u)

$\mathcal{A}(z) = -\,a\ln(bz^2+1)$ — *Li, Yang, Yuan'17*

$\mathcal{A}(z) = -\,a\ln((bz^2+1)(dz^4+1))$ — *Zhu, Chen, Zhou, Zhang, Huang'25*

CEP in holographic model

I.Aref'eva, KR'18; IA, KR, P.Slepov'21

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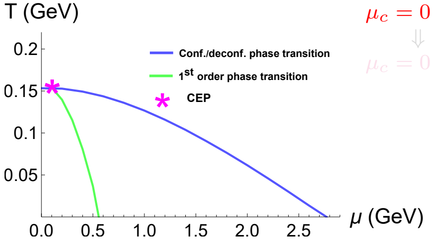
Isoropic plasma $\nu = 1$ No magnetic field $c_B = 0$

Light quarks $\mathcal{A}(z) = -a \log(bz^2 + 1)$, $f_0(z) = e^{-cz^2 - \mathcal{A}(z) + Nz + K}$



$\mu_c = 0.048$

$\Downarrow$

$\mu_c = 0.234$

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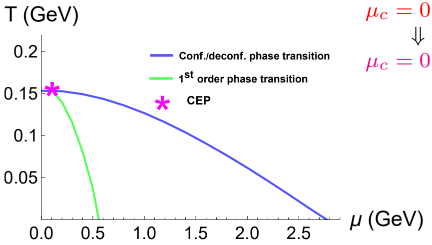

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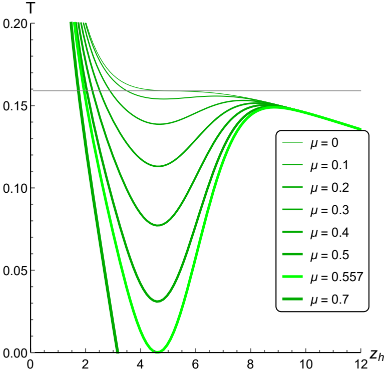

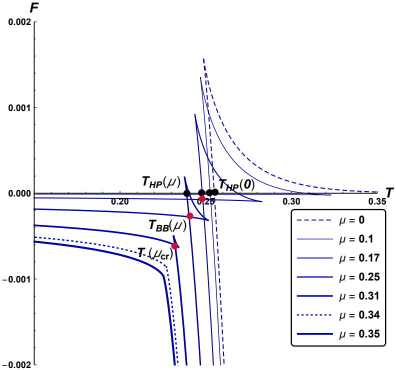

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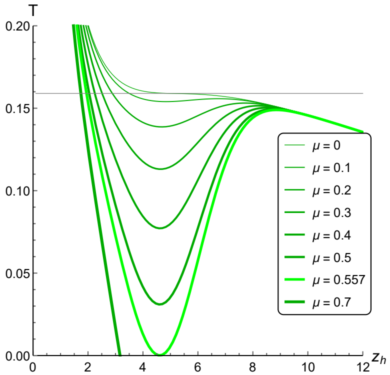

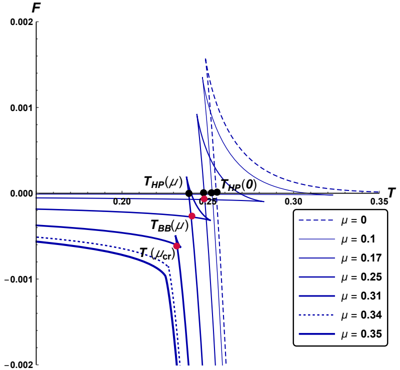

CEP in holographic model

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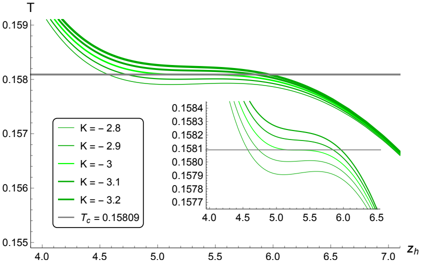
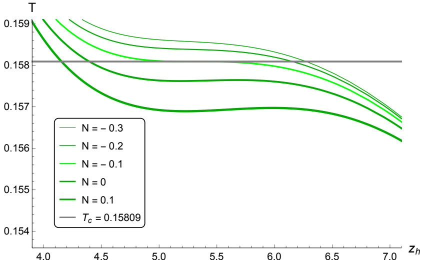
$\mu_c = 0.234 \qquad K = -3,\ N = -0.1$





Regge meson spectrum

$$\mathcal{S}_b = \frac{1}{16\pi G_5}\int d^5x\,\sqrt{-g}\left[R - \frac{f_0(\phi)}{4}F^2_{(0)} - \frac{1}{2}\partial_\mu\phi\,\partial^\mu\phi - V(\phi)\right]$$

$$\mathcal{S}_m = \frac{1}{16\pi G_5}\int d^5x\,\sqrt{-g}\left[-\frac{f_R(\phi)}{4}\left(F_V^2 + F_{\tilde{V}}^2\right) - \frac{1}{2}\partial_\mu\psi\,\partial^\mu\psi - \frac{1}{2}g_5^2\psi^2\tilde{V}^2 - U(\psi)\right]$$

$$A^L = V + \tilde{V}, \quad A^R = V - \tilde{V} \qquad \nabla_\mu[f_R(\phi)F_V^{\mu\nu}] = 0$$

$$ds^2 = \frac{e^{2\mathcal{A}_s}}{z^2}\left[-g(z)\,dt^2 + d\vec{x}^2 + \frac{dz^2}{g(z)}\right]$$

$$V_i(x,z) = \int \frac{d^4k}{(2\pi)^4}\,e^{ik\cdot x}v_i(z), \quad v_i = \left(\frac{z}{e^{\mathcal{A}_s}f_R g}\bigg|_{\mu=T=0}\right)^{1/2}\psi_i \equiv X\psi_i$$

$$-\psi_i'' + U(z)\psi_i = m^2\psi_i, \quad U(z) = \frac{2X'^2}{X^2} - \frac{X''}{X}$$

$$f_R = e^{-c_R z^2 - \mathcal{A}_s(z)}, \qquad \mathcal{A}_s(z) = -a\log(1+bz^2) + \sqrt{\frac{1}{6}}\,\phi(z)$$

$$U(z) = \frac{3}{4z^2} + c_R^2 z^2, \qquad m_n^2 = 4c_R n$$

Regge meson spectrum

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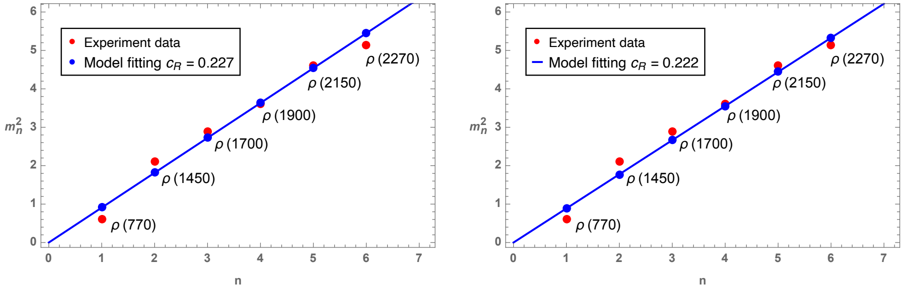

PRD 110 (2024) 030001

Conclusion

- A family of models, able to shift the CEP point (μ_c, T_c), is considered.
- The shift possibilities have a number of limitations within the simplest models.
- Regge meson spectrum can be provided via the additional gauge kinetic function, that can be possibly connected to the gauge kinetic function, associated with the μ-providing Maxwell field, in within more complex and detaild models.
- Spacial and magnetic field anisotropies will definitely influence the CEP location and possibly — Regge meson spectrum.

All these aspects require further investigaion, so to be continued...

Thank you
for your attention

Backup. Main refs

- И.Я. Арефьева, “Голографическое описание кварк-глюонной плазмы, образующейся при столкновениях тяжелых ионов”, УФН, **184:6** (2014)
- И.А., "QGP time formation in holographic shock waves model of heavy ion collisions“ TMPh, 184 (2015), 398–417
- I.A., A. Golubtsova, “Shock waves in Lifshitz-like spacetimes,” JHEP’04, 011 (2015)
- I.A. and K. Rannu, “Holographic Anisotropic Background with Confinement-Deconfinement Phase Transition,” JHEP **05** (2018) 206
- I.A., A. Golubtsova, G. Policastro, “Exact holographic RG flows and the $A_1 \times A_1$ Toda chain,” JHEP **05** (2019) 117
- I.A., K. Rannu, P. Slepov, “Orientation Dependence of Confinement-Deconfinement Phase Transition in Anisotropic Media,” Phys. Lett. **B 792** (2019) 470
- I. A., A. Patrushev, P. Slepov “Holographic Entanglement Entropy in Anisotropic Background with Confinement-Deconfinement Phase Transition”, JHEP **07** (2020) 043
- I.A., K. Rannu, P. S. Slepov, “Anisotropic solutions for a holographic heavy-quark model with an external magnetic field”, TMPh **206** (2021) 400
- I.A., A. Golubtsova, E. Gourgoulhon, “Holographic drag force in 5d Kerr-AdS black hole,” JHEP **04** (2021) 169
- I. A., K. Rannu, P. Slepov, "Holographic Anisotropic Model for Light Quarks with Confinement-Deconfinement Phase Transition”, JHEP **06** (2021) 90
- I.A., K. Rannu, P. Slepov, “Holographic Anisotropic Model for Heavy Quarks in Anisotropic Hot Dense QGP with External Magnetic Field,” JHEP **07**(2021) 161
- I.A., A.Ermakov, P.Slepov, “Direct photons emission rate and electric conductivity in twice anisotropic QGP holographic model with first-order phase transition,” EPJC **82** (2022) 85

Backup. Main refs

- I.A., A. Ermakov, K. Rannu and P. Slepov, “Holographic model for light quarks in anisotropic hot dense QGP with external magnetic field,” EPJC **83** (2023) 79
- K. Rannu, ”Phase Transition of Anisotropic Hot Dense QGP in Magnetic Field: z^5-term Holography for Heavy Quarks”, arXiv:2405.07881 [hep-th] (2024)
- I. Ya. Aref’eva, A. Hajilou, P. Slepov, M. Usova, ”Running coupling for holographic QCD with heavy and light quarks: Isotropic case”, Phys. Rev. D **110**, 126009 (2024)
- И.Я. Арефьева, А. Хаджилу, П.С. Слепов, М.К. Усова, ”Бета-функция в голографических моделях КХД”, ТМФ (2024), т. 221, № 3, стр. 615–628
- И.Я. Арефьева, К.А. Ранну, П.С. Слепов, ”Голографические анизотропные модели Эйнштейна с дилатоном и четырьмя полями Максвелла”, ТМФ (2025), т. 222, № 1, стр. 161–177
- I.Ya. Aref’eva, A. Hajilou, P. Slepov, M. Usova, ”Beta-functions and RG flows for holographic QCD with heavy and light quarks: Isotropic case”, Phys. Rev. D **111**, 046013 (2025)