Cornell potential for anisotropic QGP with non-zero chemical potential

K.A. Rannu

Peoples Friendship University of Russia (RUDN)
Steklov Mathematical Institute (MI RAS)

RUDN university

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in collaboration with I.Ya. Aref'eva and P. Slepov

Motivation

Holography needs

- Natural theory with metric as solution of EOM.
- Description of anisotropic QGP.
- Non-zero chemical potential $\mu \neq 0$ (NICA).

I. Ya. Aref'eva **"Holography for HIC at LHC and NICA"**
EPJ Web Conf. **164** 01014 (2017)

Action in Einstein frame, metric ansatz

$$S = \frac{1}{16\pi G_5} \int d^5x \sqrt{-g} \times$$
$$\times \left[R - \frac{f_1(\phi)}{4} F_{(1)}^2 - \frac{f_2(\phi)}{4} F_{(2)}^2 - \frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) \right]$$

$$A_\mu^{(1)} = A_t(z)\delta_\mu^0 \qquad F^{(2)} = q\ dy^1 \wedge dy^2 \qquad \phi = \phi(z)$$

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

Boundary conditions:

$$g(0) = 1,\ g(z_h) = 0 \qquad A_t(0) = \mu,\ A_t(z_h) = 0 \qquad \phi(z_h) = 0$$

I.A., K.R. JHEP **1805** 206 (2018)

Solution for anisotropic metric ansatz

$$b(z) = \exp(cz^2/2) \;\Rightarrow\; \text{heavy quarks}$$

$$f_1 = z^{-2+\frac{2}{\nu}} \qquad A_t(z) = \mu\,\frac{e^{-\frac{cz^2}{4}} - e^{-\frac{cz_h^2}{4}}}{1 - e^{-\frac{cz_h^2}{4}}}$$

$$g(z) = 1 - \frac{z^{2+\frac{2}{\nu}}}{z_h^{2+\frac{2}{\nu}}}\,\frac{\mathfrak{G}(\frac{3}{4}cz^2)}{\mathfrak{G}(\frac{3}{4}cz_h^2)} - \frac{\mu^2 c\, z^{2+\frac{2}{\nu}} e^{\frac{cz_h^2}{2}}\,\mathfrak{G}(cz^2)}{4\left(1 - e^{\frac{cz_h^2}{4}}\right)^2}\left(1 - \frac{\mathfrak{G}(cz_h^2)}{\mathfrak{G}(cz^2)}\,\frac{\mathfrak{G}(\frac{3}{4}cz^2)}{\mathfrak{G}(\frac{3}{4}cz_h^2)}\right),$$

$$\mathfrak{G}(x) = x^{-1-\frac{1}{\nu}}\;\gamma\left(1 + \frac{1}{\nu}, x\right) = \sum_{n=0}^{\infty}\frac{(-1)^n\,x^n}{n!(1+n+\frac{1}{\nu})}$$

Solution for anisotropic metric ansatz

$$\phi = \frac{1}{2\sqrt{2}\,\nu}\left\{\sqrt{3c^2\nu^2 z^4 - 18c\,\nu^2 z^2 + 8\,(\nu-1)}\; - \right.$$

$$- \sqrt{3c^2\nu^2 z_h^4 - 18c\,\nu^2 z_h^2 + 8\,(\nu-1)} + 2\sqrt{2\,(\nu-1)}\,\ln\left(\frac{z^2}{z_h^2}\right)$$

$$- 3\sqrt{3}\,\nu\,\ln\left(\frac{\sqrt{3c^2\nu^2 z^4 - 18c\,\nu^2 z^2 + 8\,(\nu-1)} - \sqrt{3}\,\nu\,(3 - cz^2)}{\sqrt{3c^2\nu^2 z_h^4 - 18c\,\nu^2 z_h^2 + 8\,(\nu-1)} - \sqrt{3}\,\nu\,(3 - cz_h^2)}\right) \; -$$

$$- 2\sqrt{2\,(\nu-1)}\;\times$$

$$\left.\times\;\ln\left(\frac{9c\,\nu^2 z^2 - 8\,(\nu-1) - \sqrt{2\,(\nu-1)}\,\sqrt{3c^2\nu^2 z^4 - 18c\,\nu^2 z^2 + 8\,(\nu-1)}}{9c\,\nu^2 z_h^2 - 8\,(\nu-1) - \sqrt{2\,(\nu-1)}\,\sqrt{3c^2\nu^2 z_h^4 - 18c\,\nu^2 z_h^2 + 8\,(\nu-1)}}\right)\right\}$$

Stable solution $\Rightarrow c < 0$

Confinement-deconfinement in hot anisotropic media

$$\mathcal{DW}_x \equiv cz + \frac{1}{\nu z}\sqrt{\frac{2}{3}}\,\phi' + \frac{g'}{2g} - \frac{2}{z}\Big|_{z=z_{DWx}} = 0$$

$$\mathcal{DW}_y \equiv cz + \frac{1}{\nu z}\sqrt{\frac{2}{3}}\,\phi' + \frac{g'}{2g} - \frac{\nu+1}{\nu z}\Big|_{z=z_{DWy}} = 0$$

$$\mathcal{DW}_\theta \equiv cz + \frac{1}{\nu z}\sqrt{\frac{2}{3}}\,\phi' + \frac{g'}{2g} - \frac{2}{z} + \left(1 - \frac{1}{\nu}\right)\frac{z^{1-\frac{2}{z}}\sin^2(\theta)}{\cos^2(\theta) + z^{2-\frac{2}{\nu}}\sin^2(\theta)}\Big|_{z=z_{DW\theta}} = 0$$

I.A, K.R., P.S. PLB **792** 470 (2019)

Confinement/deconfinement phase transition for $\nu = 1$

$$b(z) = \exp(cz^2/2) \qquad \mathbf{c = ?}$$

Heavy Quarks:

$\nu = 1$ 1-st order phase transition $T(\mu = 0) = 0.6$ GeV

*Y. Yang, P.-H. Yuan JHEP **1512** 161 (2015)*

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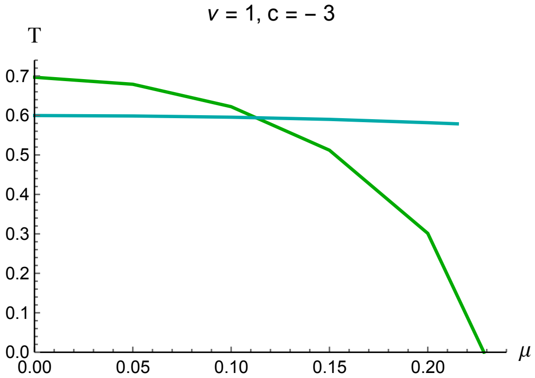

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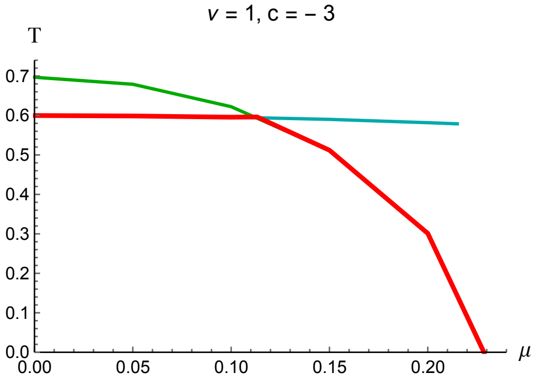
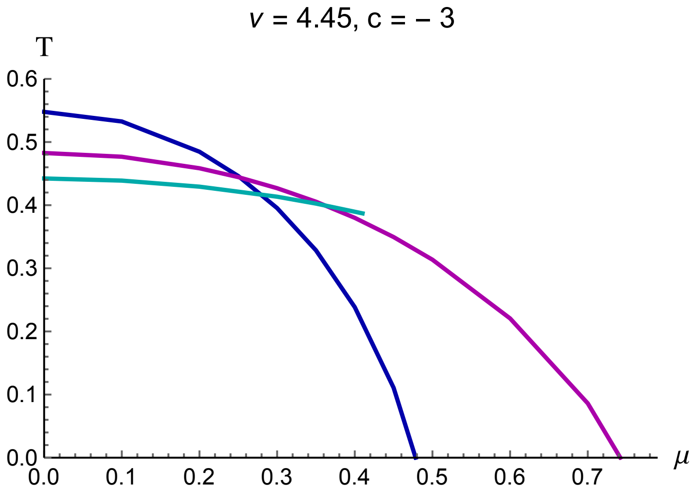


Confinement/deconfinement phase transition for $\nu = 4.45$



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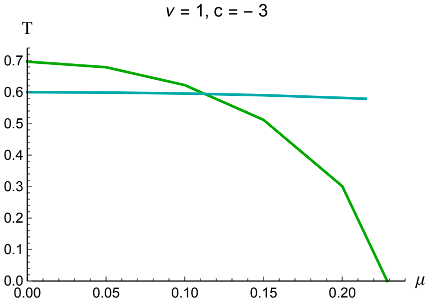
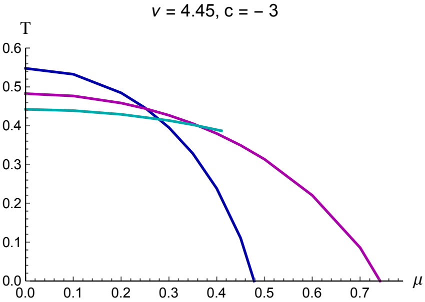
Anisotropy: $T\downarrow, \;\; \mu_{max}\uparrow$





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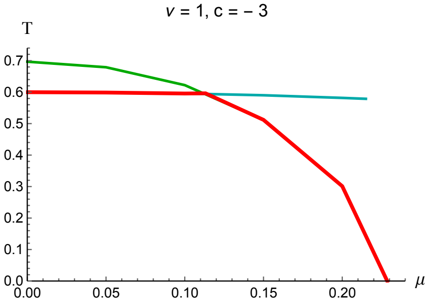
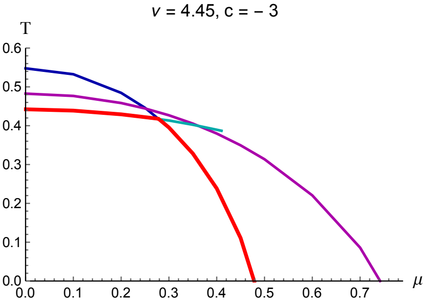




String tension

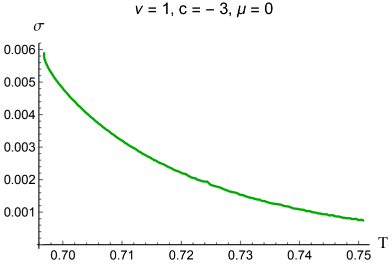
$$\sigma_{DW} = z^{-2} e^{\frac{cz^2}{2}+\sqrt{\frac{2}{3}}\phi(z_{DW})} \sqrt{g(z_{DW})\left(\cos^2(\theta) + z^{2+\frac{2}{\nu}}\sin^2(\theta)\right)}$$

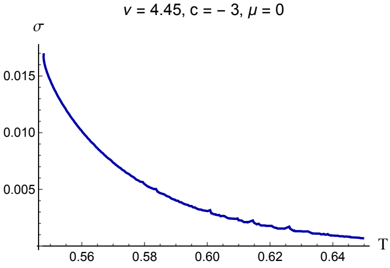
$$\sigma_{DWx} = z^{-2} e^{\frac{cz^2}{2}+\sqrt{\frac{2}{3}}\phi(z_{DWx})} \sqrt{g(z_{DWx})}$$

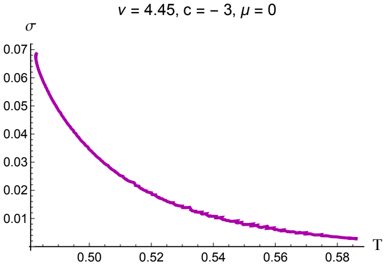
$$\sigma_{DWy} = z^{-1-\frac{1}{\nu}} e^{\frac{cz^2}{2}+\sqrt{\frac{2}{3}}\phi(z_{DWy})} \sqrt{g(z_{DWy})}$$

$$z_{DW} = Z_{min} : \ \sigma'\big|_{z=z_{min}} = 0$$

String tension







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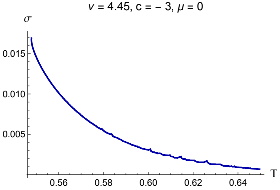
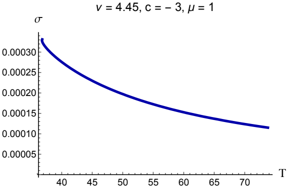
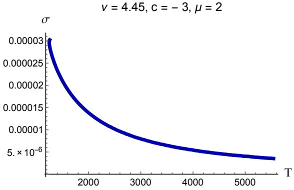
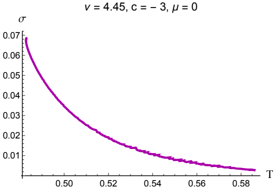
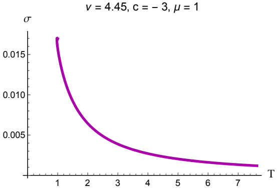
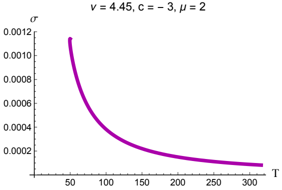




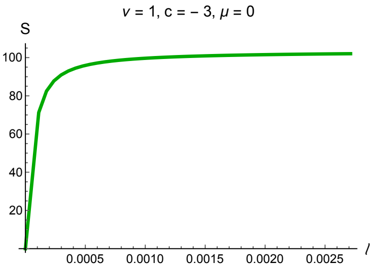


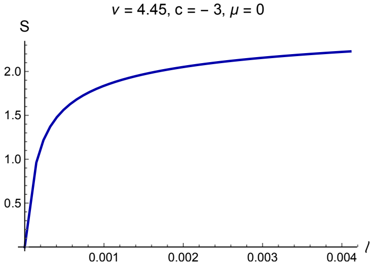


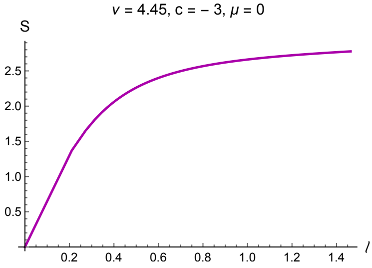




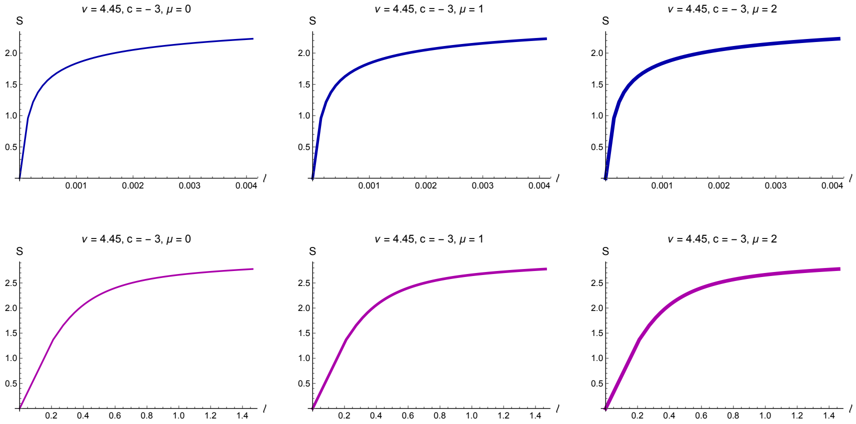
Cornell potential







Cornell potential



Conclusions

Anisotropy changes

- phase diagram for confinement/deconfinement phase transition,
- string tension,
- Cornell potential.

Quark mass influences on

- phase diagram for confinement/deconfinement phase transition,
- string tension,
- Cornell potential.

Chemical potential influences on

- string tension,
- coefficients of the Cornell potential for heavy quarks (weakly).

To do

- Light quarks $b(z) = exp(-a\ln(cz^2+1))$.
- Anisotropy for strong magnetic field.
- Shock waves.
- RG-flow.

Thank you
for your attention

Parameters

Holographic model $\leftrightarrow$ $\beta(E)$-function (HRG)

L — scale
ν — anisotropy
c — quark mass
μ — chemical potential