Potentials in the modified spaces AdS_5 with moderate increase in entropy

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based on

I. Ya. Aref'eva, E. O. Pozdeeva and T. O. Pozdeeva, Holographic estimation of multiplicity and membranes collision in modied spaces AdS5. *TMPh,* **176**(1): 861–872 (2013).

I. Ya. Aref'eva, E. O. Pozdeeva and T. O. Pozdeeva, Holographic estimation of multiplicity and membranes collision in modied spaces AdS5, arXiv:1401.1180 [hep-th].

I. Ya. Aref'eva, E. O. Pozdeeva and T. O. Pozdeeva. Potentials in modified spaces AdS_5 with moderate increase in entropy, in press 2014.

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Introduction

- Quark-gluon plasma (QGP) was opened at Au-Au ion collisions by RHIC collaboration in 2005.
- Accordingly to the holographic approach the formation of (QGP) in the four-dimensional space corresponds to a black hole creation in a dual five-dimensional space. Analogy exists between the colliding heavy ions and colliding gravitational shock waves in the (d+1) anti-de Sitter space. At that particular creation multiplicity at heavy ion collisions is proportional to the entropy or the trapped surface area of the black hole in the auxiliary space.

J. M. Maldacena, *Adv. Theoret. Math. Phys.*, **2**, 231–252 (1998); arXiv:hep-th/9711200v3 (1997).

S. S. Gubser, I. R. Klebanov, and A. M. Polyakov, *Phys. Lett. B*, **428**, 105–114 (1998); arXiv:hep-th/9802109v2 (1998).

E. Witten, *Adv. Theoret. Math. Phys.*, **2**, 253–291 (1998); arXiv:hep-th/9802150v2 (1998).

- From experimental data it is known that the particle creation multiplicity is being appropriate approximated by the power function of the form $s_{NN}^{0.15}$ at energies from 102 GeV to 104 GeV. At the case of the AdS5 space the particle creation multiplicity is proportional
- to $s_{NN}^{1/3}$ [*]. To reproduce the experimental dependence in the holographic approach Kiritsis and Taliotis [**] have proposed to modify the AdS5 space by introduction of the *b*-factors

- [*] S. S. Gubser, S. S. Pufu, and A. Yarom, ArXive: 0805.1551.
- I.Arefeva, Bagrov, Guseva JHEP 0912 (2009) 009
- [**] E. Kiritsis and A. Taliotis, JHEP, 04 (2012); A. Taliotis, JHEP, 05 (2013).

Formulation of the problem

The modified AdS5 background metric

$$ds^2 = b(z)^2(dz^2 + dx^i dx^i + dx^+ dx^-), \quad i = 1, 2$$

$$b(z) = \left(\frac{L}{z}\right)^a$$

If a=1, we have the case of the AdS5 space

$$b(z) = e^{-\frac{z}{R}}, \quad R \sim \Lambda_{QCD}^{-1} \sim 1\,fm$$

$$b(z) = \left(\frac{L}{z}\right)^a e^{-\frac{z^2}{R^2}}$$

- We consider the action of the five-dimensional gravity coupled to a scalar dilaton field:

$$S_5 = S_R + S_\Phi,$$

S_R is the Einstein-Hilbert action with the negative cosmological constant

$$S_R = -\frac{1}{16\pi G_5}\int \sqrt{-g}\left(R + \frac{d(d-1)}{L^2}\right)dx^5$$

S_Φ is the dilaton action

$$S_\Phi = -\frac{1}{16\pi G_5}\int \sqrt{-g}\left(-\frac{4}{3}(\partial\Phi)^2 + V(\Phi)\right)dx^5$$

Solving the Einstein equation and scalar field equation

$$\Phi' = \pm\frac{3}{2}\sqrt{\frac{2b'^2}{b^2} - \frac{b''}{b}}, \quad V(\Phi(z)) = \frac{3}{b^2}\left(\frac{b''}{b} + \frac{2b'^2}{b^2} - \frac{4b^2}{L^2}\right)$$

So we can try to get the explicit form of $V(\Phi)$

$$b(z) = e^{-\frac{z}{R}}, \quad R \sim \Lambda_{QCD}^{-1} \sim 1\,fm$$

$$V\left(\Phi\right) = -\frac{12}{L^2} + \frac{9}{R^2} e^{\pm 4\left(\Phi - \Phi_0\right)/3}$$

$$b(z)=\left(\frac{L}{z}\right)^{a}$$

$a>1$

$$V(\Phi)=-\frac{12}{L^2}+\frac{9}{R^2}e^{\pm\frac{4}{3}\left(\sqrt{\frac{(a-1)}{a}}(\Phi-\Phi_0)\right)}$$

$a<1$

$$\tilde{V}(\Phi_p)=-\frac{12}{L^2}+\frac{9}{R^2}e^{\pm\left(\frac{4}{3}\sqrt{\frac{(1-a)}{a}}(\Phi_p-\Phi_{p0})\right)}$$

$$S_{\Phi p}=-\frac{1}{16\pi G_5}\int\sqrt{-g}\left(-\frac{4}{3}\left(\partial\Phi_p\right)^2+\tilde{V}(\Phi_p)\right)dx^5$$

The similar expressions for phantom field

$$\Phi'_p=\pm\frac{3}{2}\sqrt{\frac{b''}{b}-\frac{2b'^2}{b^2}},\quad \tilde{V}(\Phi_p(z))=\frac{3}{b^2}\left(\frac{b''}{b}+\frac{2b'^2}{b^2}-\frac{4b^2}{L^2}\right)$$

$$\Phi-\Phi_0=i\left(\Phi_p-\Phi_{p0}\right)$$

$$b(z) = \left(\frac{L}{z}\right)^a e^{-\frac{z^2}{R^2}}$$

For this factor it is rather difficult to construct the dependence of $V(\Phi)$

However, the dependence of $V(\Phi)$ can be represented parametrically

If $a < 1$ at $z < z_0.$

We have a theory with an alternative sine of the kinetic term. And the scalar field can be represented as

$$\Phi = \Phi_s \theta\left(z - z_0\right) + i\Phi_p \theta\left(z_0 - z\right)$$

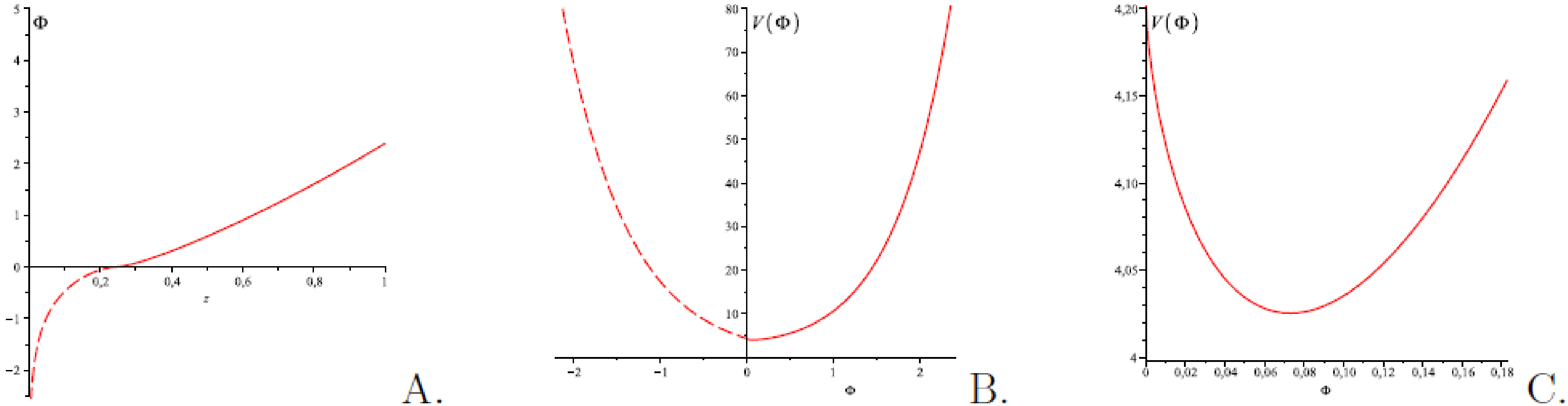


Figure 3: The plots corresponding to $a = 1/2$, $L = 4.4$ fm, R=1 fm and a sign plus in (17). A. The phantom Φ_p (dashed line) and dilaton Φ_s (solid line) fields as functions of z. B. The dependence of the potential V on the dilaton and the phantom fields. C. The same dependence of the potential V on the dilaton field as in B for small Φ.

To deal with a point-like shock wave we add an action of a point-like source moving along a trajectory

$$x^{\mu} = x_{*}^{\mu}(\eta)$$

η Is an arbitrary world-line parameter

$$S_{st} = \int \frac{1}{2\sqrt{-g}} g_{\mu\nu} \frac{dx_{*}^{\mu}}{d\eta} \frac{dx_{*}^{\nu}}{d\eta} d\eta$$

The Einstein equation for the particle in dilaton field has the form:

$$\left(R_{\mu\nu} - \frac{g_{\mu\nu}}{2}R\right) - \frac{g_{\mu\nu}}{2}\left(-\frac{4}{3}(\partial\Phi_s)^2 + V(\Phi_s)\right) - \frac{4}{3}\partial_\mu\Phi_s\,\partial_\nu\Phi_s - g_{\mu\nu}\frac{d(d-1)}{2L^2} = 8\pi G_5 J_{\mu\nu},$$

where $$J_{++} = \frac{E}{b^3(z)}\,\delta(x^1)\delta(x^2)\delta(z-z_*)\delta(x^+).$$

The shock wave metric modified by wrapping factor

$$ds^2 = b^2(z)\big(dz^2 + dx^i\,dx^i - dx^+\,dx^- + \phi(z,x^1,x^2)\delta(x^+)(dx^+)^2\big)$$

E. Kiritsis, A. Taliotsis ArXiv:1111.1931

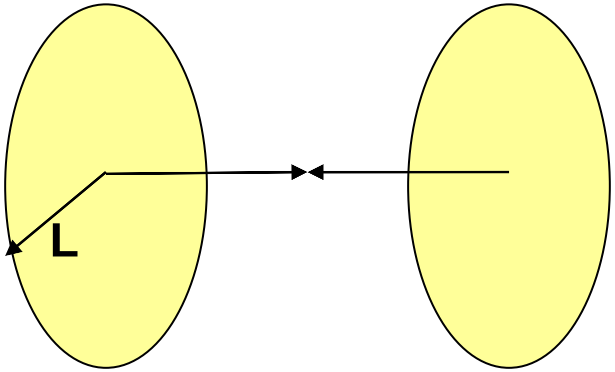
Using shock ansatz we reduce the Einstein equation to the differential equation for shock wave profile and two equations defining the connection of field and field potential with b-factor:

$$\left(\partial^2_{x^1} + \partial^2_{x^2} + \partial^2_z + \frac{3b'}{b}\partial_z\right)\phi(z, x_\perp) = -16\pi G_5 \frac{E}{b^3}\,\delta(x^1)\delta(x^2)\delta(z_* - z)$$

$$V(\Phi_s) = \frac{3}{b^2}\left(\frac{b''}{b} + \frac{2(b')^2}{b^2} - \frac{4b^2}{L^2}\right)$$

$$\Phi'_s = \pm\frac{3}{2}\sqrt{\left(\frac{2(b')^2}{b^2} - \frac{b''}{b}\right)}$$

Below the shock wave with averaged mass over the transversal surface is called the domain wall



S. Lin, E. Shuryak, Phys. Rev. D, 79:12 (2009), 124015, 12 pp., arXiv: 0902.1508; 83:4 (2011), 045025, 14 pp., arXiv: 1011.1918.

I. Y. Aref'eva, A. A. Bagrov, E. O. Pozdeeva, JHEP, 05 (2012), 117, 34 pp., arXiv: 1201.6542.

The equation for the wave profile domain for the dimension with b-factor in the case of average mass over the finite region with a radius L

$$\left(\partial_z^2 + \frac{3b_z}{b}\partial_z\right)\phi^\omega(z) = -\frac{16\pi G_5 E}{L^2}\frac{\delta(z - z_*)}{b^3(z)},$$

L is the domain radius, za and zb are boundary points of the trapped surface,

z_* is a point of collision

The conditions of the trapped surface formation lead to additional equations for the wave profile in the domain boundary points

$$\partial_z\phi^\omega \,|_{z=z_a} = 2, \qquad \partial_z\phi^\omega \,|_{z=z_b} = -2$$

Minimum entropy of a black hole can be estimated due to the trapped surface area

$$S \geq S_{trapped} = \frac{A_{trapped}}{4G_N}, \quad S_{trapped} = \frac{\int \sqrt{det|g_{AdS_3}|} dz dx_{\perp}}{2G_5}$$

We calculate the relative entropy proportional to the relative area of the trapped surface

$$s = \frac{S_{trap}}{\int d^2 x_{\perp}}$$

R. Penrose, unpublished, 1974

It is assumed that the Penrose hypothesis is true in the case of AdS_5

$$b(z) = e^{-\frac{z}{R}};$$

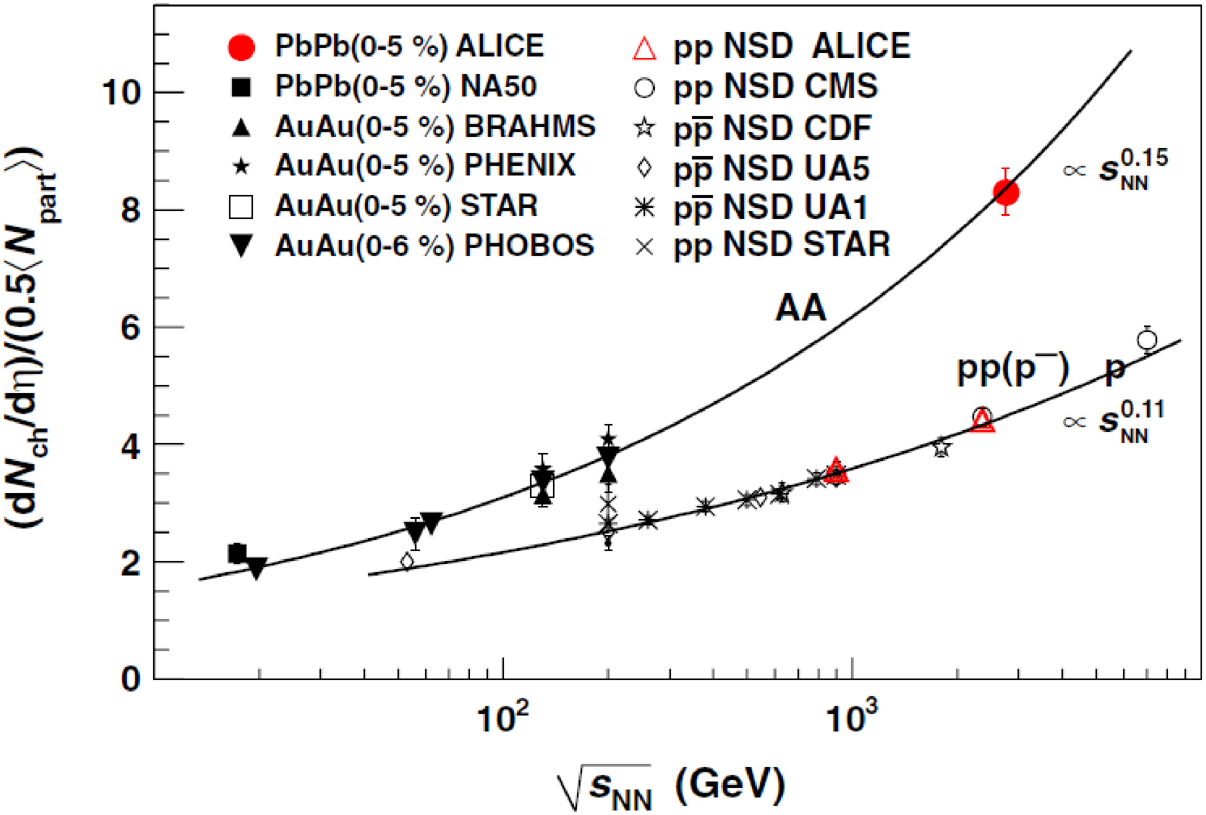
$$S \sim \sqrt{s_{NN}}$$

$$b(z) = \left(\frac{L}{z}\right)^{a}, \quad a \approx 0.47;$$

$$S \sim s_{NN}{}^{0.15}$$

$$b(z) = \left(\frac{L}{z}\right)^{a} e^{-\frac{z^2}{R^2}};$$

$$S \sim s_{NN}{}^{0.15} \ln\left(\sqrt{S_{NN}}\right)$$



K. Aamodt et al. [ALICE Collaboration], arXiv:1011.3916 [nucl-ex].

Charged particle pseudo-rapidity density per participant pair for central nucleus as a function of a centre-of-mass energy per nucleon pair

The model with power-law wrapping factor can coinside with experimental data at a≈0.47

Conclusion

•In the cases of good agree with experiment (*a* < 1), we found that in the spaces with power-law *b*-factor the scalar field is phantom one and in the space with the modernized mix $b = (L/z)^a e^{-z^2/R^2}$ the scalar field is phantom at the interval $z < z0$ and dilaton at the interval $z > z0$.

The power-law factor for $a \approx 0.47$ allows to modulate the dependence of multiplicity of the produced particles on the energy of the colliding heavy-ions.

•In the future we plan to study another properties of quark-gluon plasma such as spectrum, the temperature dependence of the break in string between quarks

- Thank you for attention