Mini-Black Holes at LHC

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Outlook

- Applications:

- *Dual description of QGP(Quark Gluon Plasma)*
- QGP in dual description;
- Trapped surface area and multiplicity;
- BH charge and chemical potential

IV. Dual description of QGP(Quark Gluon Plasma)

Black Hole production in AdS_5
as Quark-Gluon-Plasma formation in 4-dim QCD

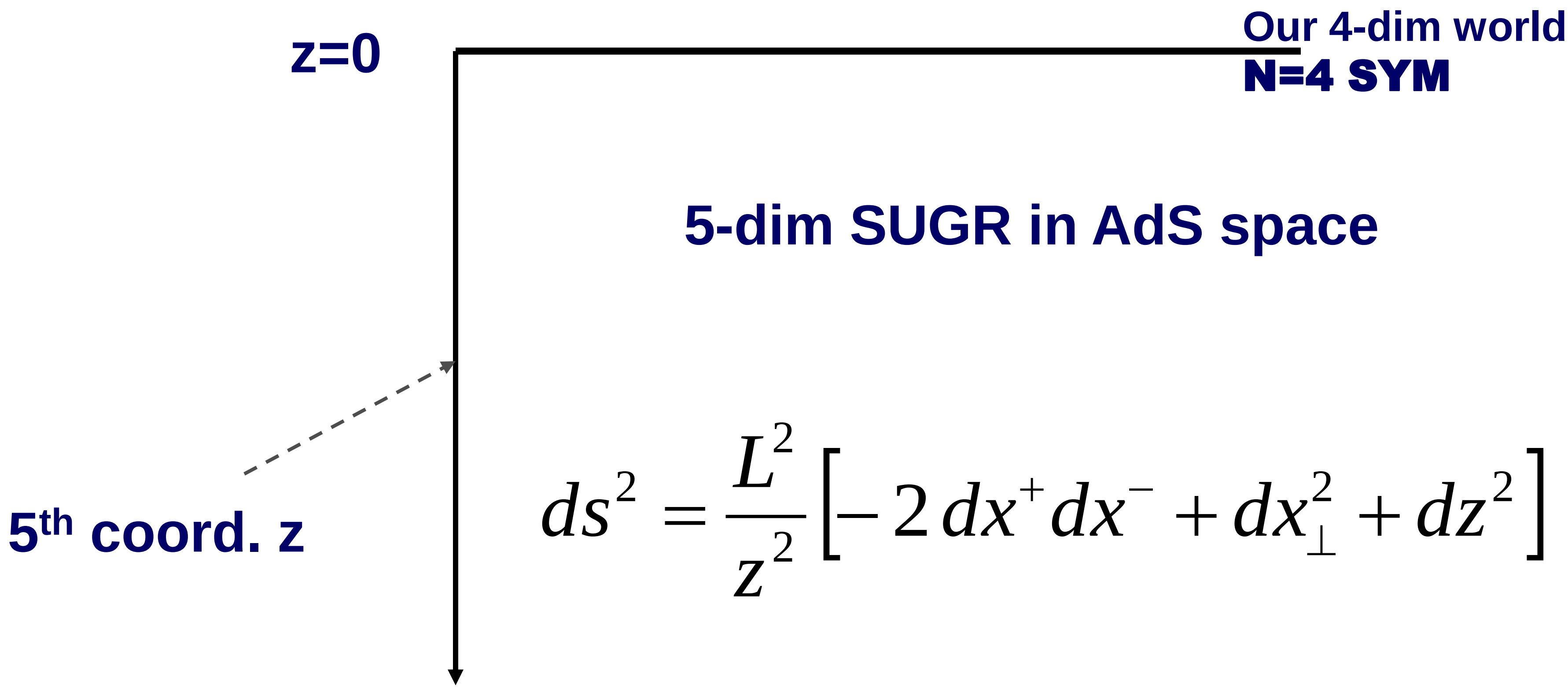
Goal: construct colliding nuclei in a holographic dual to QCD **(an exact holographic dual to QCD is unavailable)**

Conjecture: Total entropy production in a heavy-ion collision = entropy of a trapped surface.

$$S \geq S_{\text{trapped}} \equiv \frac{A_{\text{trapped}}}{4G_5}$$

Nastase, hep-th/0501068; Shuryak, Sin, Zahed; Grumiller, Romatschke; Albacete, Kovchegov,Taliotis(09)

Shock-waves in AdS$_5$ & 4-dim QCD



5-dim SUGR in AdS space

$$ds^2 = \frac{L^2}{z^2}\left[-2\,dx^+ dx^- + dx_\perp^2 + dz^2\right]$$

$$x^\pm = \frac{x^0 \pm x^3}{\sqrt{2}}$$

L is the radius of the AdS space

$\Lambda = -6/L^2$

AdS/CFT dictionary + BH thermodynamics

In the phenomenological model of QGP, (Landau or Bjorken hydrodynamical models) t he plasma is characterized by the **energy-momentum tensor**

$$T_{\mu\nu}$$

$$ds^2 = \frac{L^2}{z^2}\left[-2\,dx^+dx^- + dx_\perp^2 + dz^2\right]$$

$$ds^2_{pert} = \frac{L^2}{z^2}\left[ds^2_M + z^4 T_{\mu\nu}dx^\mu dx^\nu + dz^2\right]$$

BH in AdS

$\varepsilon - energy$

$p - presure$

$\mu - chemical\ \ potential$

$T - temperature$

$s - entropy$

$M - Arnowitt - Deser - Misner$

$\mu = Q$ *charge*

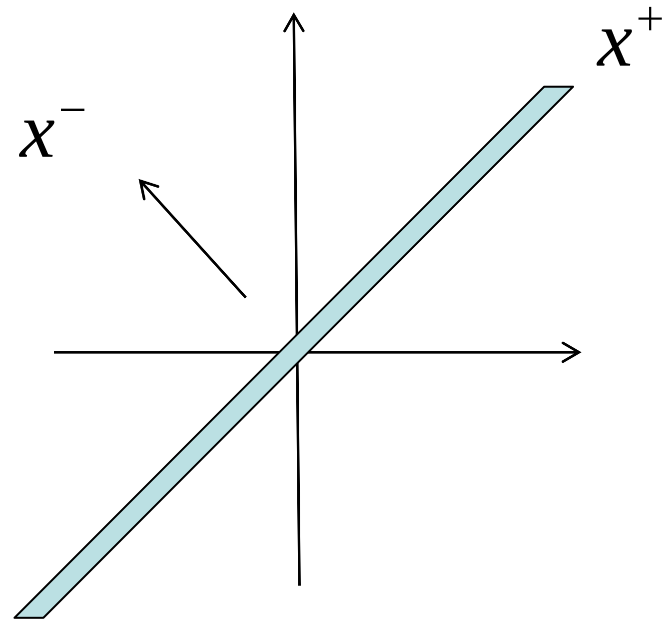
$T - Hawking\ \ tempera\ \ ture$

$S - entropy\ (area\ of\ \ horizon)$

Single Nucleus in AdS/CFT

An ultrarelativistic nucleus is a shock wave in 4d with the energy-momentum tensor

$$\langle T_{--} \rangle \sim \mu \, \delta(x^-)$$



The metric of a shock wave in AdS corresponding to the ultrarelativistic nucleus in 4d is

$$ds^2 = \frac{L^2}{z^2}\left[-2\, dx^+ dx^- + \frac{2\pi^2}{N_C^2} \langle T_{--}(x^-) \rangle \, z^4 \, dx^{-2} + dx_\perp^2 + dz^2 \right]$$

Janik, Peschanksi '05

Multiplicity

$$S_{\text{trapped}} \approx \pi \left(\frac{L^3}{G_5} \right)^{1/3} (2EL)^{2/3}$$

Gubser, Pufu, Yarom, 0805.1551,
Alvarez-Gaume, C. Gomez, Vera,
Tavanfar, and Vazquez-Mozo, 0811.3969

GQP = BH

$$\epsilon = \frac{3\pi^3}{16} \frac{L^3}{G_5} T^4$$

$\Longrightarrow$ $$\frac{L^3}{G_5} \approx 1.9$$

Lattice calculations

$$\frac{\epsilon}{T^4} \approx 11$$

$$S \geq S_{\text{trapped}} \approx 35000 \left(\frac{\sqrt{s_{NN}}}{200 \text{ GeV}} \right)^{2/3}.$$

Multiplicity

$$S_{\text{trapped}} \approx \pi \left(\frac{L^3}{G_5}\right)^{1/3} (2EL)^{2/3}$$

Gubser, Pufu, Yarom, 0805.1551,
Alvarez-Gaume, C. Gomez, Vera,
Tavanfar, and Vazquez-Mozo, 0811.3969

GQP = BH $\quad \frac{L^3}{G_5} = \frac{16ET^4}{3\pi^3} \quad \Longrightarrow \quad \frac{L^3}{G_5} \approx 1.9$

Lattice calculations $\quad ET^4 \approx 11$

$$EL|_{Au-Au,\sqrt{s_{NN}}=200\,\text{GeV}} \approx 4.3 \times 10^5\,,$$

$$EL|_{Au-Au,\sqrt{s_{NN}}=5.5\,\text{TeV}} \approx 1.27 \times 10^7$$

$$S \geq S_{\text{trapped}} \approx 35000 \left(\frac{\sqrt{s_{NN}}}{200\ \text{GeV}}\right)^{2/3}$$

Profile from AdS

$$\langle T_{uu} \rangle = \frac{L^2}{4\pi G_5} \lim_{z \to 0} \frac{1}{z^3} \Phi(z, x_\perp) \delta(u)$$

$$\langle T_{uu} \rangle = \frac{2L^4 E}{\pi (L^2 + (x^1)^2 + (x^2)^2)^3} \delta(u)$$

L is equal to the root-mean-square transverse radius of the nucleons

in according with a Woods-Saxon profile for the nuclear density

For Pb L~4.4 fm; for Au L~4.3 fm

Multiplicity in Landau model

In the phenomenological model of QGP, (Landau or Bjorken hydrodynamical models) t he plasma is characterized by the energy-momentum tensor

$\varepsilon - energy$

$p - presure$

$\mu = 0$

$T - temperature$

$s - entropy$

$$0 = \varepsilon - Ts + p$$

$$p = \frac{1}{3}\varepsilon$$

$$\frac{4}{3}\varepsilon = Ts$$

$$d\varepsilon = Tds$$

$$\frac{d\varepsilon}{\varepsilon} = \frac{4}{3}\frac{ds}{s}$$

$$s = \varepsilon^{3/4} \Rightarrow S = V\varepsilon^{3/4} \Rightarrow$$

$$E = \varepsilon V \qquad S = E^{3/4}V^{1/4} \Rightarrow S \sim E^{1/2} \sim s_{NN}^{1/4}$$

$$V \sim \frac{m_0}{E}$$

Different profiles and multiplicities

An arbitrary gravitational shock wave in *AdS5*

$$ds^2 = \frac{L^2}{z^2}\left(-dx^+dx^- + dx_\perp^2 + \phi(x_\perp, z)\delta(x^+)dx^{+2} + dz^2\right)$$

Plane shock waves

Lin and Shuryak, 09

$$\phi(x_\perp, z) = \phi(z)$$

The Einstein equation

$$(\partial_z^2 - \frac{3}{z}\partial_z)\phi(z) = -16\pi G_5 \mu \frac{z_0^3}{L^3}\ \delta(z - z_0)$$

Dilaton shock waves

Cai,Ji,Soh, gr-qc/9801097

IA, 0912.5481

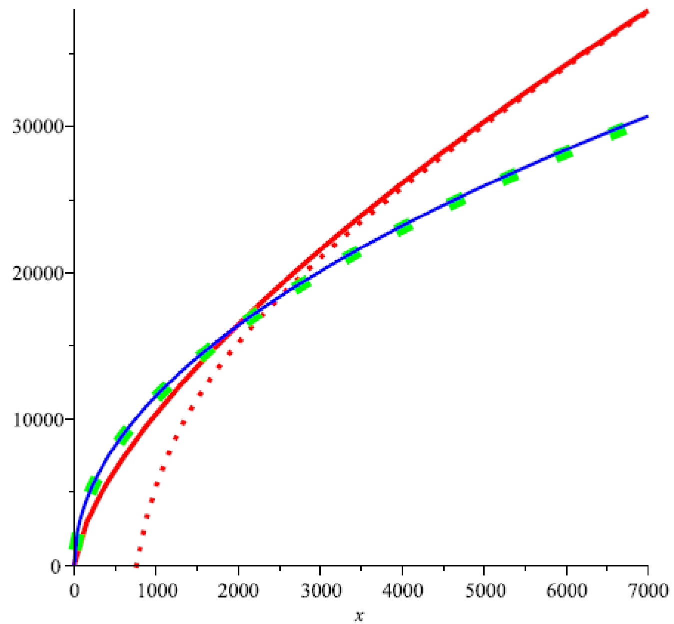
$b(r)^2$

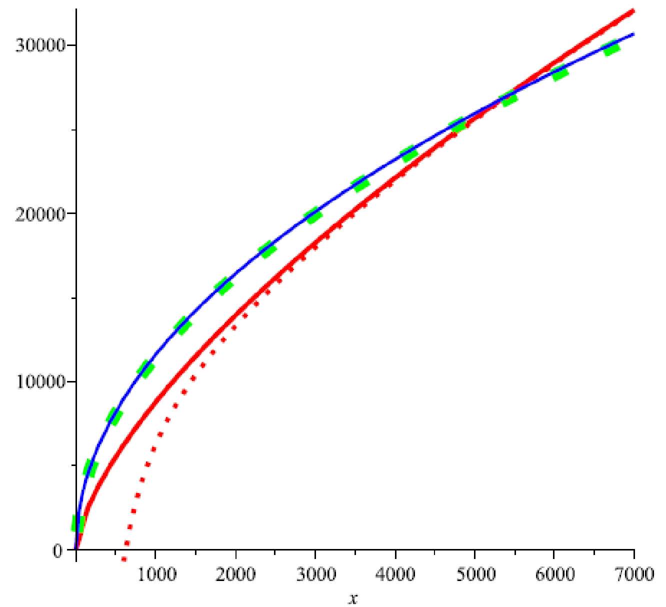
$$\left(\nabla_\perp^2 + 3\frac{b'}{b}\partial_r + \partial_r^2\right)$$

Kiritis,Taliotis, 1111.1931

Ultrarelativistic charges in (A)dS

Formation of trapped surfaces on the past light cone is only possible when $Q<Q_{cr}$

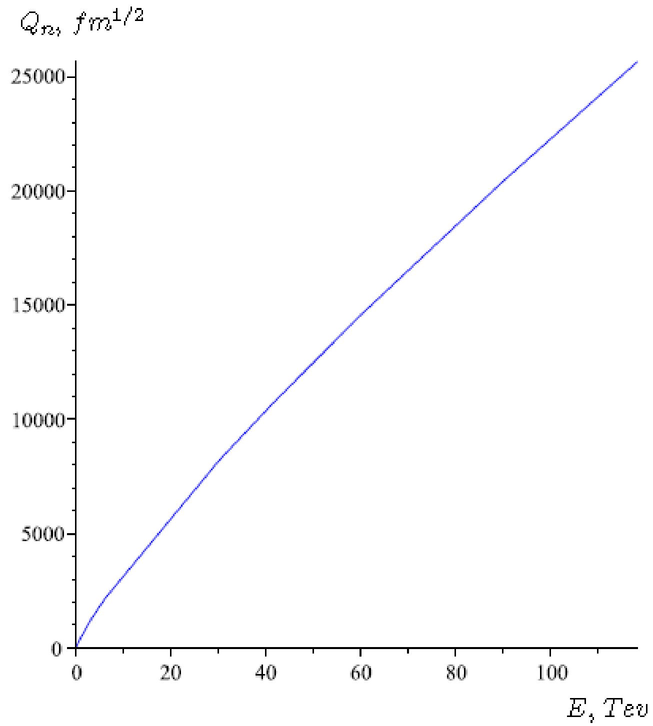


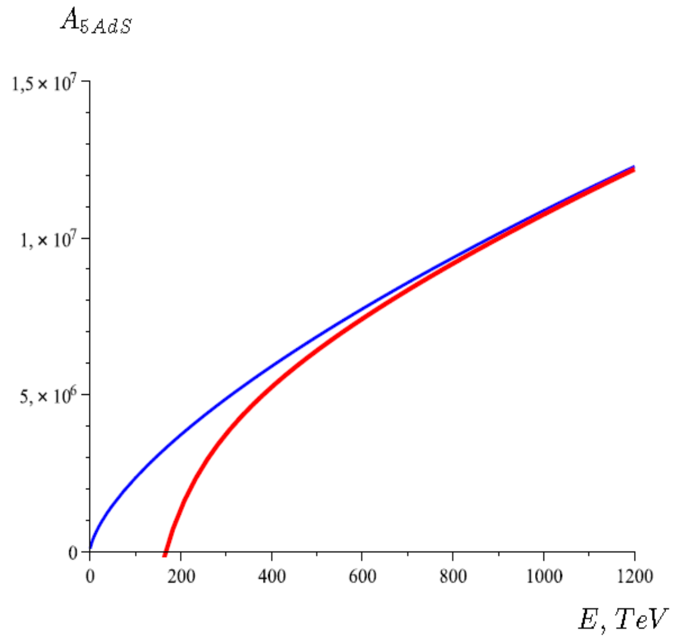


IA, A.Bagrov, L.Joukovskaya, JHEP (2010) (charged particles in AdS,dS)

Holographic phase diagram of QGP formed in heavy-ions collisions

I.A., A.Bagrov, E.Pozdeeva, 1201.6542





$$Q_n = 2 \cdot 10^6 fm^{1/2}$$

$$(\mathrm{A{=}208})\ \text{ at } \sqrt{s_{NN}} = 5.5\ \mathrm{TeV}$$

$$E_{\mathrm{beam}} = 570\ \mathrm{TeV}$$

Conclusion

- **BH production in AdS5 as QGP formation in 4-dim QCD**
- **Techniques of trapped surfaces**

Plans for future

- Classification of shock waves (to get details formula for multiplicity for heavy-ion collisions at RHIC and LHC)
- Try to use plane gravitational waves to calculate multiplicity
- Simplification of techniques of trapped surface
- May be numerical calculations in AdS5 with “stars”