Holographic Wilson loops in anisotropic QGP

Ageev D.
Steklov Mathematical Institute

Joint work with
I. Aref'eva, A.Golubtsova, E. Gourgoulhon

AdS/CFT correspondence and QGP

- Makes it possible to calculate observables in strongly-coupled QFT (at zero and finite temperature) using gauge/gravity duality away from equilibrium.
- The «dictionary» how to calculate observables.

Part of AdS/CFT «dictionary»

- Black hole in AdS ~ Temperature in dual theory
- Classical fields in AdS ~ Local operators in dual theory.
- Process of BH formation ~ thermalization in dual theory.
- Strings with special boundary conditions ~ Wilson (Polyakov e.g.) operators in dual theory.

- <u>**Deformation of AdS (AdSBH) such we match the experimental data.**</u>

Part of AdS/CFT «dictionary»

- In this talk we focus on the spatial Wilson loop operators and study the thermalization of rectangular spatial Wilson loop with one «infinite» extent (for example in Y-direction).

$$\mathcal{W}(X,Y) = \langle \mathrm{Tr} e^{i \oint_{X\times Y} dx_\mu A_\mu} \rangle = e^{-\mathcal{V}(X)Y}$$

How to mimic heavy ions collision in gauge/gravity duality?

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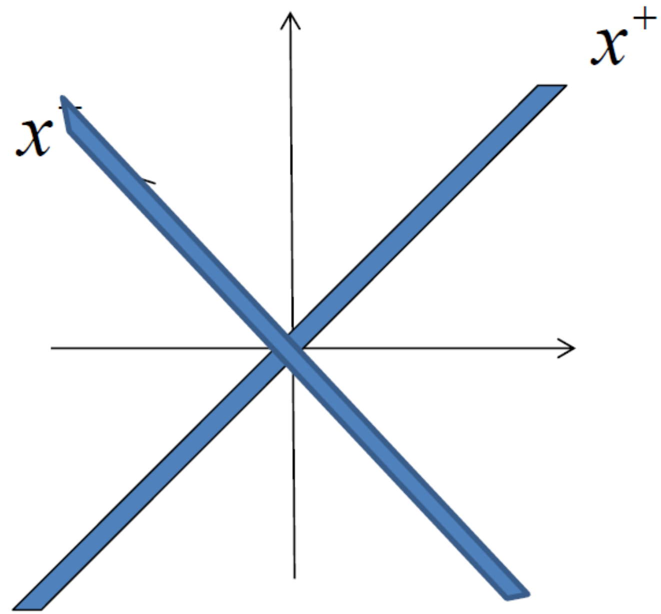
$$\langle T_{++} \rangle \sim \mu\, \delta(x^+)$$

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



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

Multiplicity

- In the holographic approach is hardest to calculate with good fitting of the experimental data.
- Main conjecture: black hole entropy formed in shock-wave collision is proporional to the multiplicity

$$\mathcal{M}_4 \sim S_5$$

Multiplicity:holography

The simplest holographic model: $s_{NN}^{1/3}$

IHQCD inspired model $s_{NN}^{\delta_1} \ln^{\delta_2} s_{NN}$

Reproducing beta-function etc: $\delta_1 \approx 0.225, \quad \delta_2 \approx 0.718$

Landau theory: $s_{NN}^{0.25}$

Experimental data: $s_{NN}^{0.15}$

Introducing Lifshitz-like metrics (anisotropy!)

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

$$s \sim \frac{\nu}{4G_5} (8\pi G_5)^{2/(\nu+2)} E^{2/(\nu+2)}$$

To get $s \sim E^{0.3}$ $\boxed{\nu = 4}$

Introd. Anisotropy and temperature

- Blackened anisotropic metric (solution of some gravity theory);hep-th/1601.06046.

$$S = \int d^5x \sqrt{|g|} \left(R[g] + \Lambda - \frac{1}{2} \nabla_m \phi \nabla^m \phi - \frac{1}{4} e^{\lambda \phi} F_{(2)}^2 \right)$$

$$ds^2 = \frac{-f(z)dt^2 + dx^2}{z^2} + \frac{dy_1^2 + dy_2^2}{z^{2/\nu}} + \frac{dz^2}{z^2 f(z)}$$

$$f = 1 - mz^{2/\nu + 2}$$

Make it in nonequilibrium

- Smoothly interpolates between T=0 background and black hole(like) solution

$$dv = dt + \frac{dz}{f(z)}$$

$$f(z,v) = 1 - \frac{m}{2}\left(1 + \tanh\frac{v}{\alpha}\right) z^{\frac{2}{\nu}+2}$$

$$ds^2 = -z^{-2} f(v,z) dv^2 - 2z^{-2} dv dz + z^{-2} dx^2 + z^{-2/\nu}(dy_1^2 + dy_2^2)$$

Non-local operators

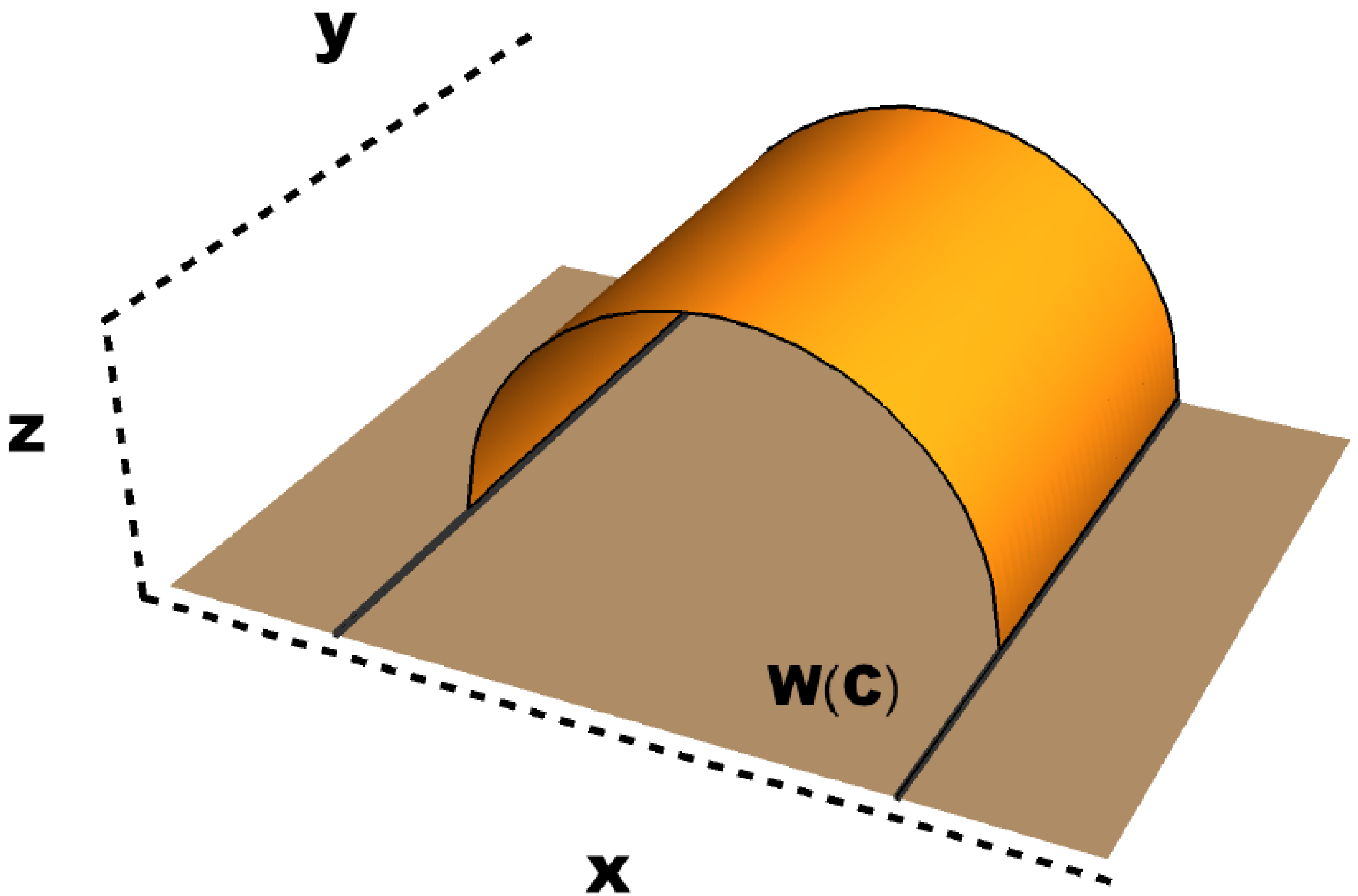
- Wilson operators are dual to the string hanging from the contour under consideration from boundary to the bulk (Maldacena,hep-th/9803002)

$$W[C] = \langle \mathrm{Tr}_F \, e^{i \oint_C dx_\mu A_\mu} \rangle = e^{-S_{string}[C]} =$$
$$= e^{-\mathcal{V}(X) Y}$$

$$S_{string} = \frac{1}{2\pi\alpha'} \int d\sigma^1 d\sigma^2 \sqrt{-\det(h_{\alpha\beta})}.$$

$$h_{\alpha\beta} = g_{MN} \partial_\alpha X^M \partial_\beta X^N$$

How it looks like



String

- Problem reduces to dynamical system with the following action. For example:

$$S_{x,y_{1(\infty)}} = \frac{L_y}{2\pi\alpha'} \int \frac{dx}{z^{1+1/\nu}} \sqrt{1 - f(z,v)v'^{\,2} - v'z'}$$

$$v = v(x),\ z = z(x)$$

$$z(\pm l) = 0, \quad v(\pm l) = t$$

infinite along the y_1-direction

on the xy_1 plane

$$\sigma^1 = x, \quad \sigma^2 = y_1$$

Finally:

$$z'' = \frac{2v'z'(2f(\nu+1) - \nu\partial_z f z) + v'^2\left[2f^2(\nu+1) - \nu(\partial_v f + f\partial_z f)z\right] - 2f(\nu+1)}{2\nu z}$$

$$v'' = \frac{v'^2(\nu\partial_z f z - 2f(\nu+1)) - 4(\nu+1)v'z' + 2(\nu+1)}{2\nu z}$$

$$z(\pm l) = 0, \quad v(\pm l) = t$$

$$S_{NG,ren} = -\frac{L_y}{2\pi\alpha'}\left(\int_{z_0}^{z_*}\frac{[\mathfrak{b}(z) - \mathfrak{b}(z_0)]}{z^{1+1/\nu}}dz - \nu\frac{\mathfrak{b}(z_0)}{z_*^{1/\nu}}\right)$$

$$\mathfrak{b}(z) = \frac{1}{z'}\left(\frac{z_*}{z}\right)^{1+1/\nu}$$

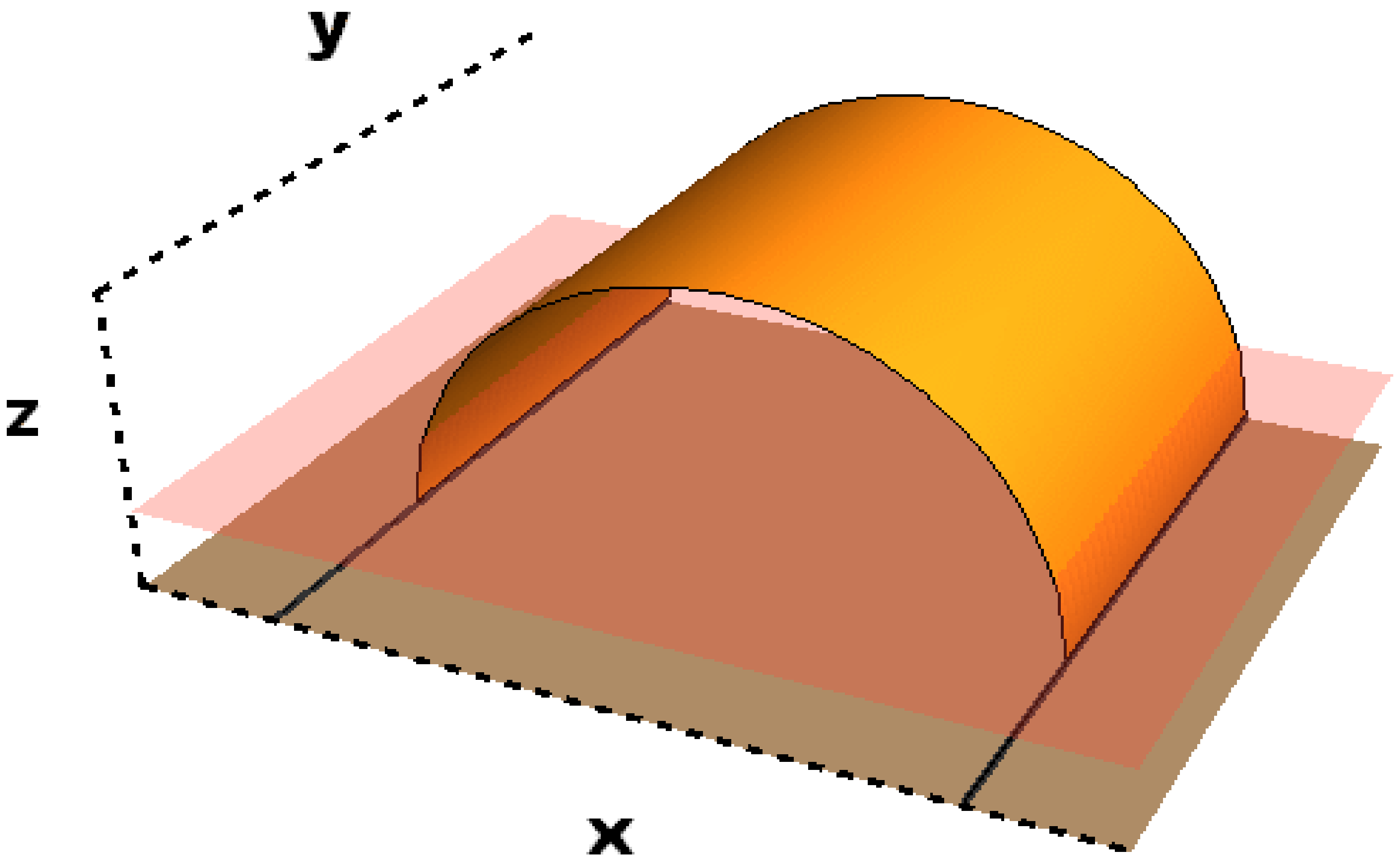
Anisotropy effect

- Longitudinal direction: $$\mathcal{V}_{x,y_{1(\infty)}} \propto -\frac{\mathcal{C}_1}{\ell^{1/\nu}}$$

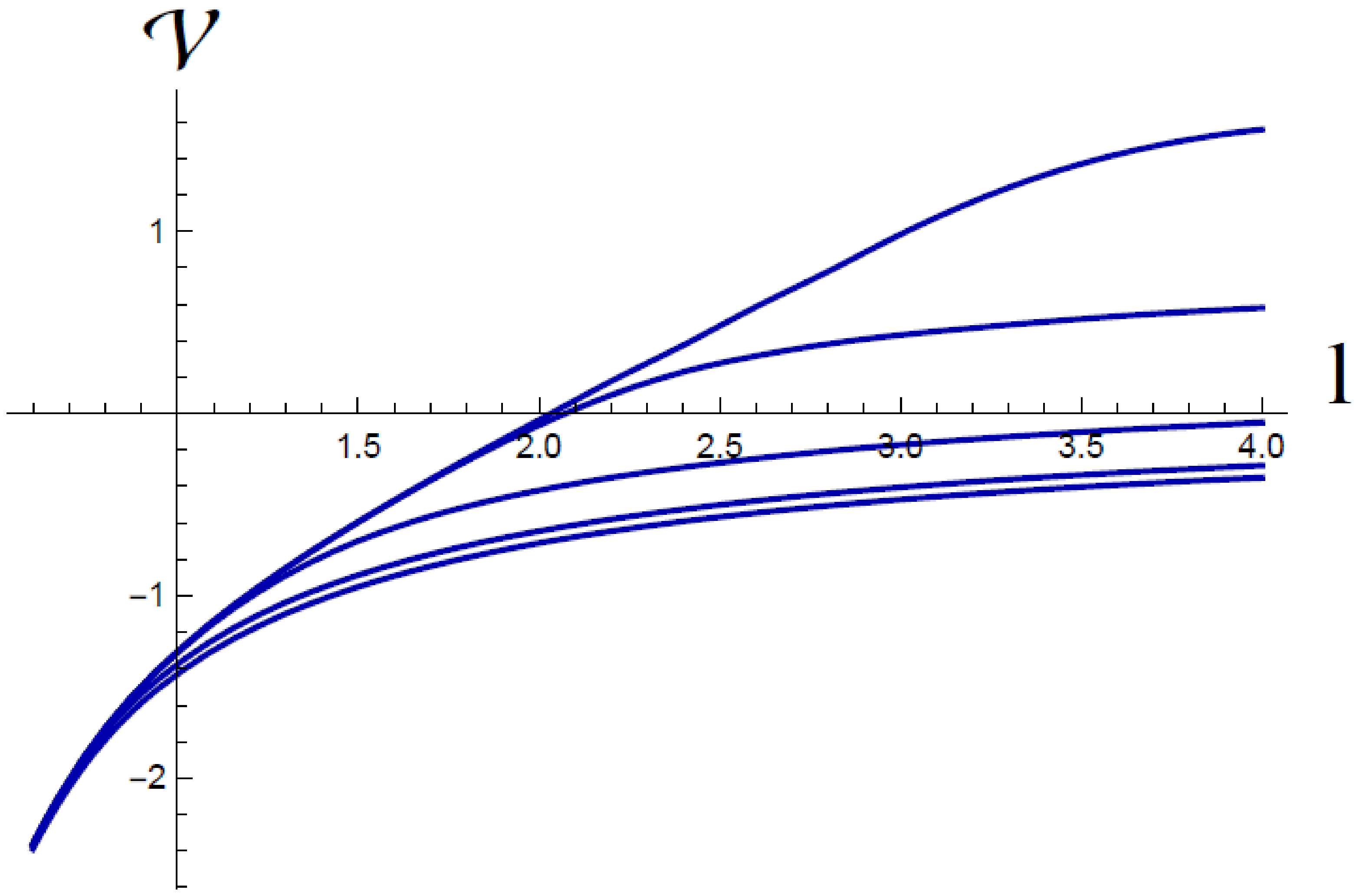
$$\mathcal{V}_{y_1,\,x_{(\infty)}} \propto -\frac{\mathcal{C}_2}{\ell^{\nu}}$$

- Transverse $$\mathcal{V}_{y_1,\,y_{2(\infty)}} \propto -\frac{\mathcal{C}_3}{\ell}$$

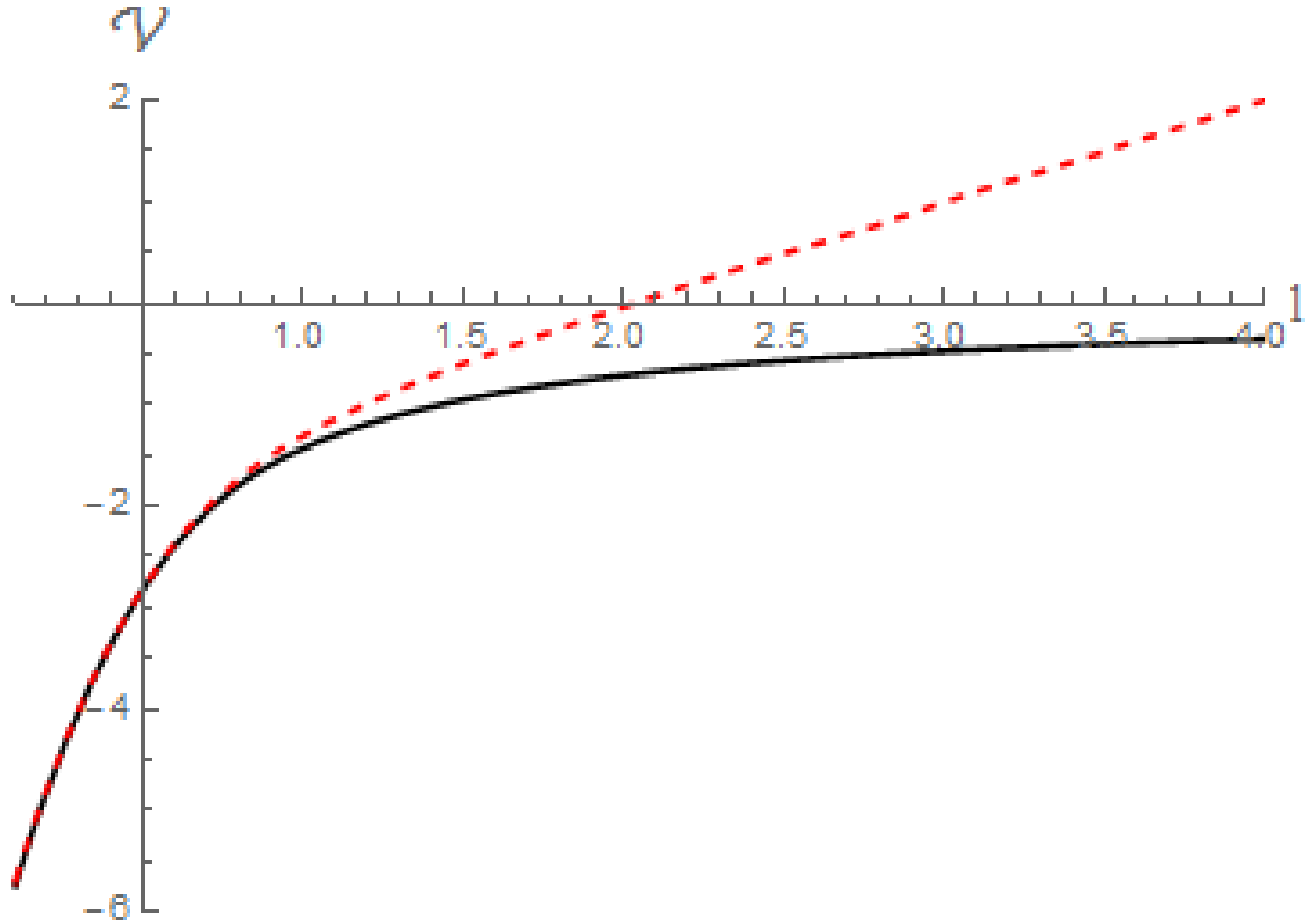
How it looks like in dynamics



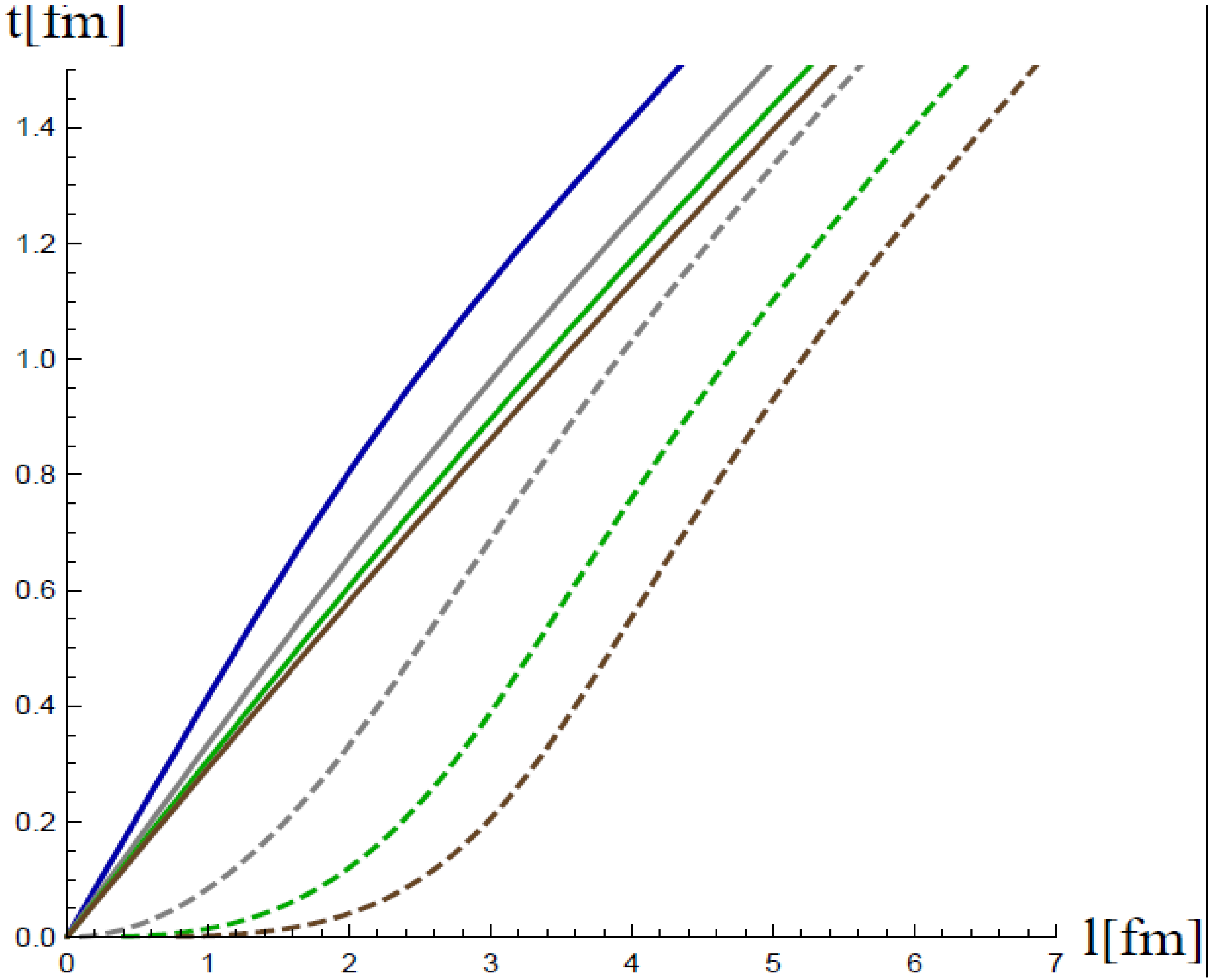
Pseudopotential at different time moments



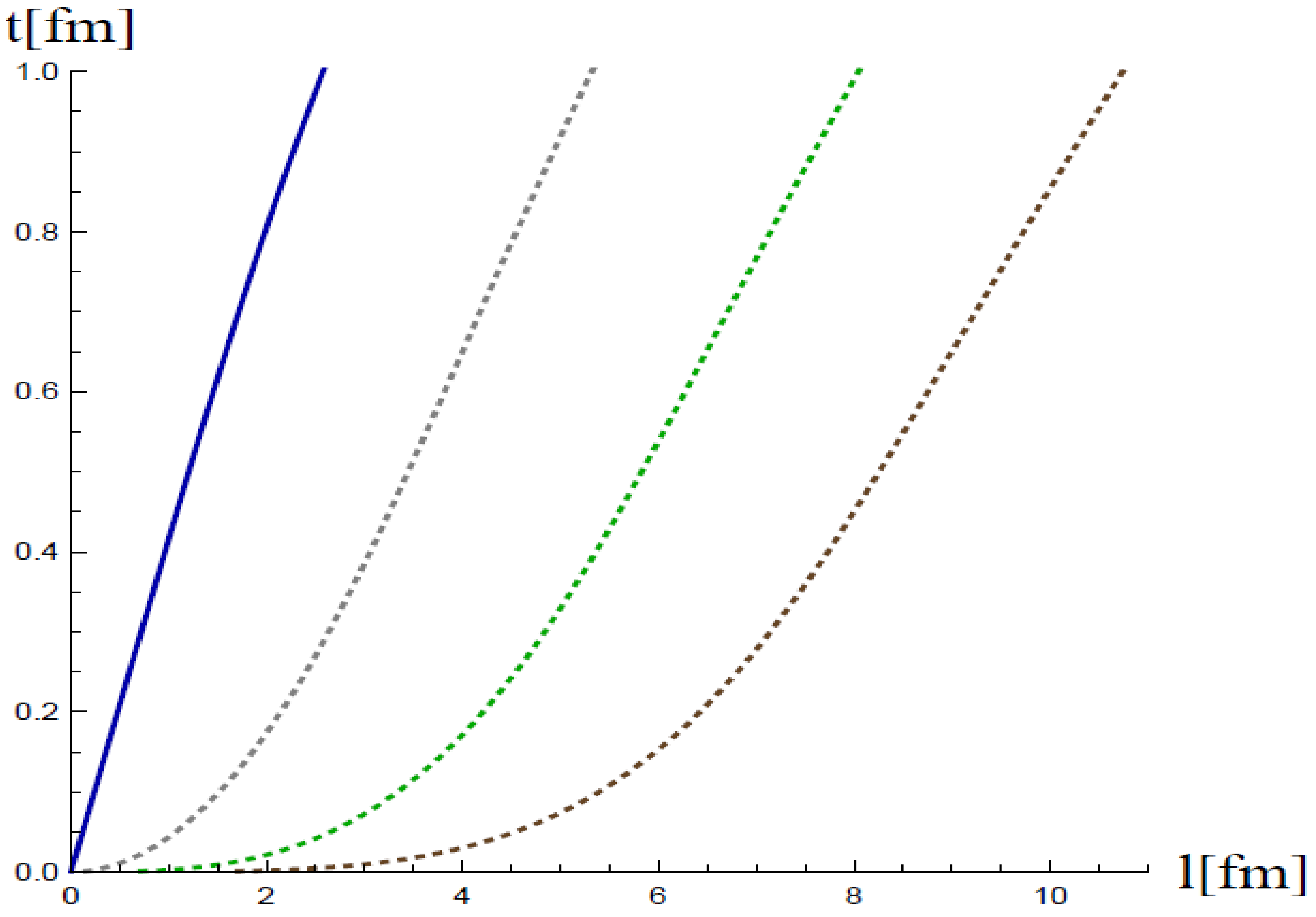
Pseudopotential thermalization



- WL's partially lying in the longitudinal direction thermalize similarly (with respect to anysotropy).



- At the same time in transversal direction anisotropy change thermalization time. Brown line is the case of parameters matching with another exp. data.



Conclusions

- In transversal direction nonlocal operators thermalization time is affected...
- ...but the Coulumb phase is conserved, in contrast to longitudinal direction.
- Qualitative dynamics are very similar in both directions
- What about nonequilibrium electric Wilson loop(quark-antiquark potential)?

Thanks for you attention!