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Tests of Fluidity of AdS/CFT Plasma Wakes

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arXiv:0712.1053 [hep-ph]

Quark Matter 2008, Jaipur, India

Outline

I. Motivation: AdS/CFT Description of Heavy Quark Jets

II. Comparison with Hydrodynamics
  - ❖ Far Away from the Jet
  - ❖ In the Vicinity of the Jet

III. Conclusions & Outlook

AdS/CFT Description of Heavy Quark Jets

- Thermalization of soft degrees of freedom at RHIC:

  - Compatible with the “perfect fluid” scenario.

  - Thermalization time < 1fm/c.

  - Strongly-coupled Quark Gluon Plasma (sQGP).

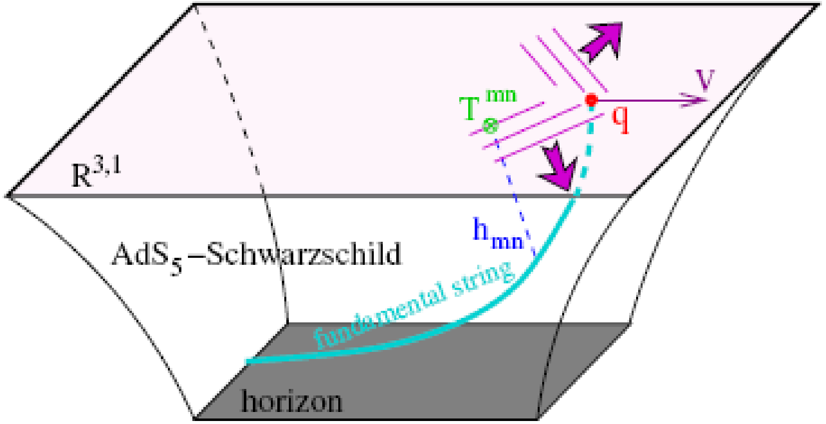
  Applicability of perturbative methods ????

AdS/CFT: Non-perturbative method to study gauge theories

What can AdS/CFT tell us about the energy deposited by heavy quark jets in HIC?

AdS/CFT Description of Heavy Quark Jets

Infinitely heavy quark moving through a static, strongly-coupled N=4 SYM plasma



$$g_{SYM} \to 0 \quad , N_c \to \infty \Longrightarrow \lambda \gg 1$$

C. P. Herzog et al., JHEP 0607, 013 (2006); S. Gubser, PRD 74, 126005 (2006);
J. J. Friess et al., PRD 75, 106003 (2007).

Comparison with Hydrodynamics

Using AdS/CFT one obtains SYM $T^{\mu\nu}$

Full solution: Only numerically

Two complementary regimes have been studied:

- Far way from the quark: K / T << 1

- Close to the quark: K / T >>1

T = Hawking temperature

J. J. Friess et al., PRD 75, 106003 (2007).

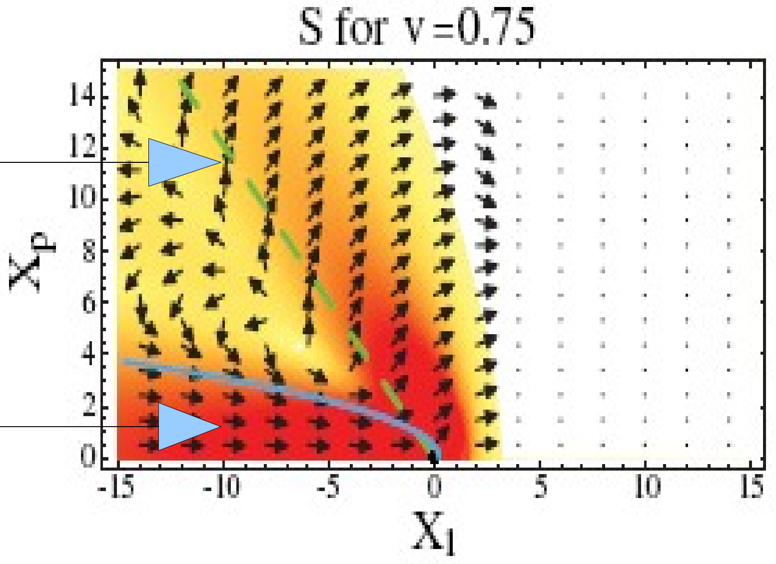
Comparison with Hydrodynamics

Far away from the quark: K / T << 1

Quark's wake has a hydrodynamical description !!!

- Mach cone

- Diffusion wake



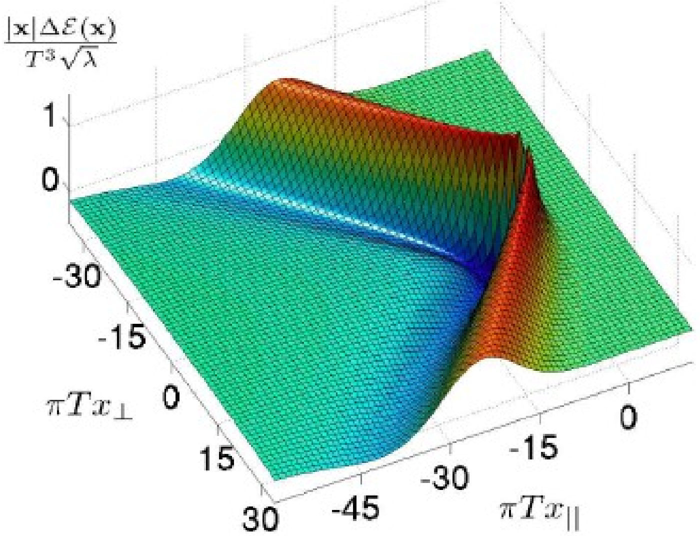
|X|~0.2 fm if T=318 MeV

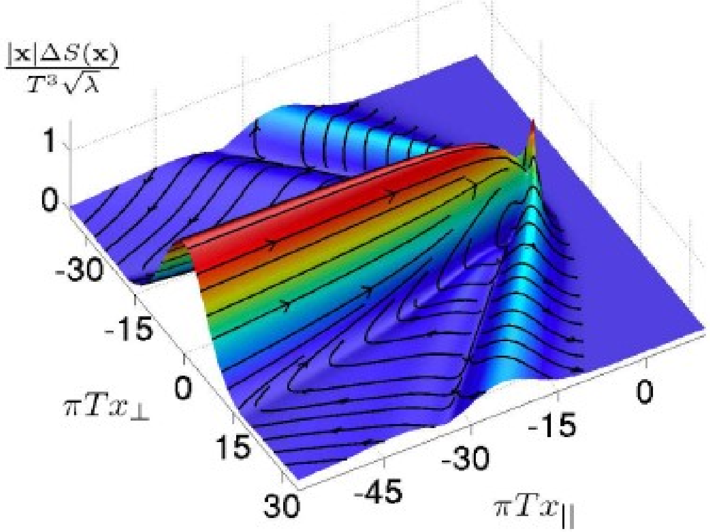
S. Gubser, S. Pufu, and A. Yarom, PRL 100, 012301 (2008).

Comparison with Hydrodynamics

Far away from the quark: K / T << 1

Hydrodynamical description works down to distances of $5/\pi T$!!!





P. Chesler, L. Yaffe, arXiv: 0712.0050 [hep-th].

Comparison with Hydrodynamics

Close to the quark: K / T >> 1

$T^{\mu\nu}$ computed analytically

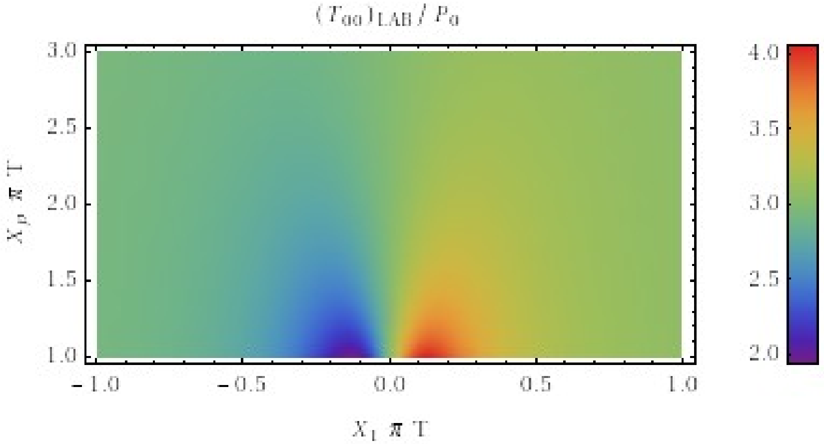
A. Yarom, PRD 75, 105023 (2007).

$$T^{Y}_{\mu\nu} = P_0\,\mathrm{diag}\{3,1,1,r^2\} + \xi\, P_0\, \Delta T_{\mu\nu}(x_1, r).$$

$$\xi = 8\sqrt{\lambda}\,\gamma_q/N_c^2 \text{ and } \gamma_q = 1/\sqrt{1-v^2}.$$

$$P_0 = N_c^2 \pi^2 T^4/8$$

Energy density (Lab)
v=0.99



Can the near quark region also be described by hydrodynamics?

Comparison with Hydrodynamics

Compare $T^{Y}_{\mu\nu}$ with $T^{NS}_{\mu\nu} = (\rho + p)\, U_\mu U_\nu + p\, g_{\mu\nu} + \Pi_{\mu\nu}$

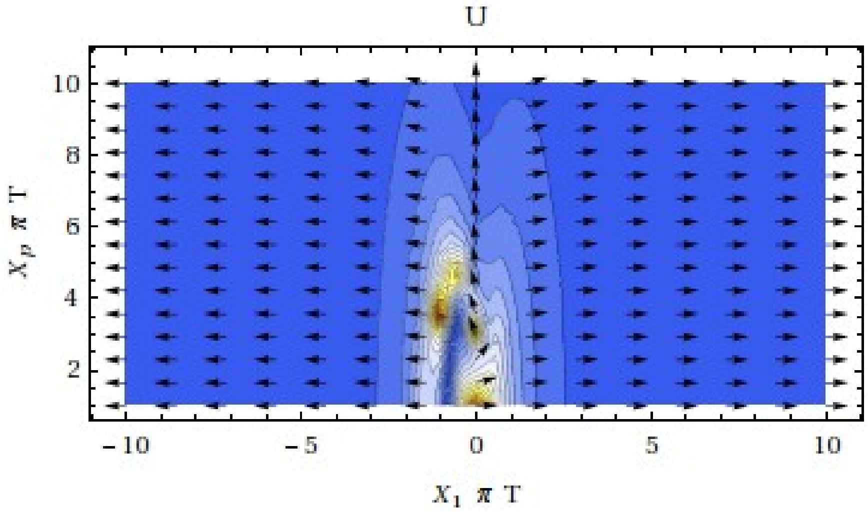
$$\frac{\eta}{s} = \frac{1}{4\pi}$$

$$\begin{aligned}\Pi^{\mu\nu} &= -\eta\left(\partial^\mu U^\nu + \partial^\nu U^\mu + U^\mu U_\alpha \partial^\alpha U^\nu\right.\\ &+ \left. U^\nu U^\alpha \partial_\alpha U^\mu\right) + \frac{2}{3}\eta\, \Delta^{\mu\nu}\left(\partial_\alpha U^\alpha\right),\end{aligned}$$

Lorentz transform $T^{Y}_{\mu\nu}$ to Landau frame to find $U^\mu = (U^0, \vec{U})$

We set v=0.99 and

$$N_c = 3,\ \lambda = 3\pi$$



Comparison with Hydrodynamics

Deviation from Navier-Stokes hydrodynamics

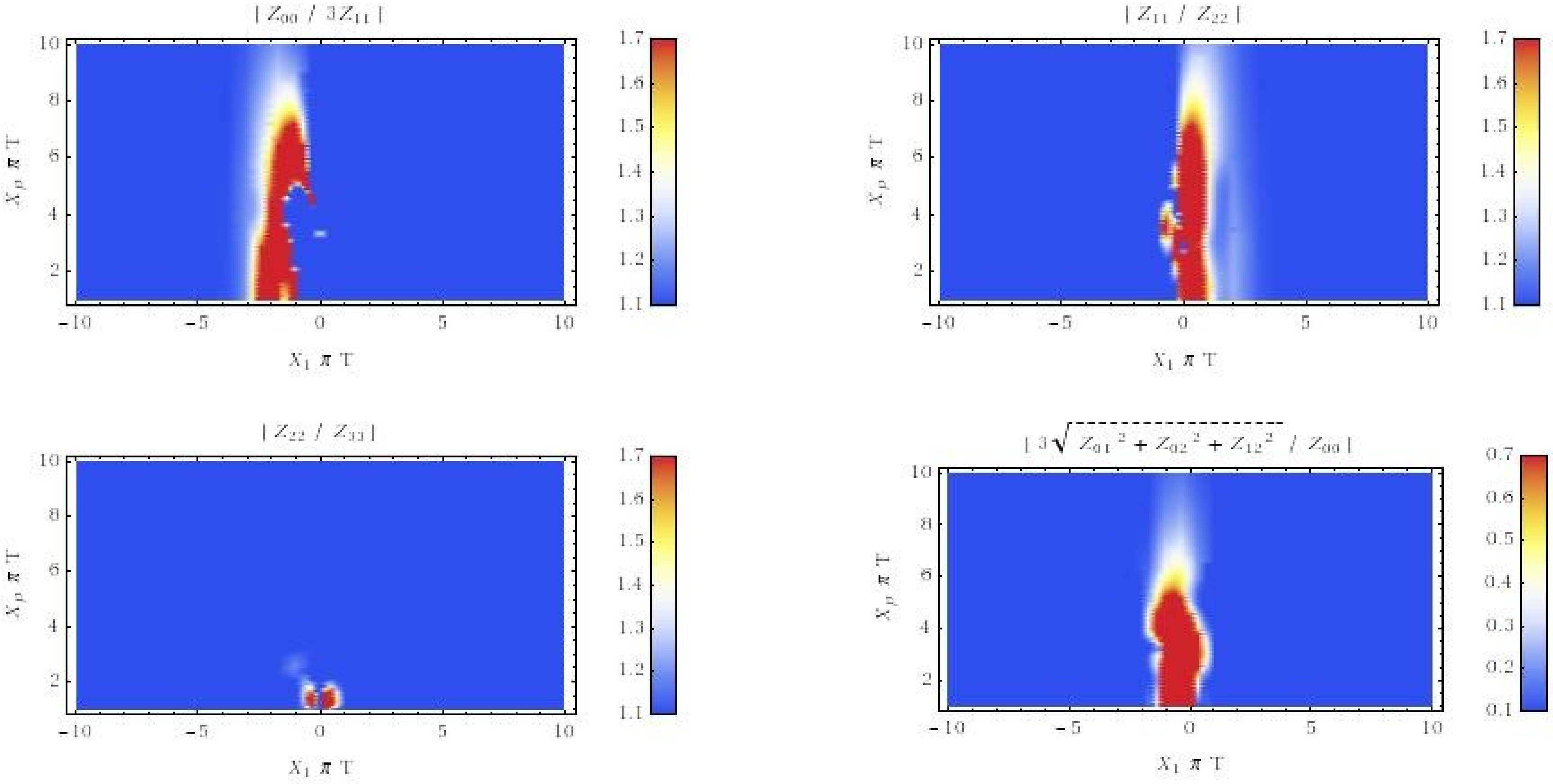
$$Z_{\mu\nu} = T^{Y}_{\mu\nu} - \Pi_{\mu\nu}$$

In the regions where $T^{Y}_{\mu\nu}$ is a solution of Navier-Stokes

In the Landau frame

$$\left(Z_{11}\right)_L = \left(Z_{22}\right)_L = \left(Z_{33}\right)_L = \frac{1}{3}\left(Z_{00}\right)_L \qquad \left(Z_{ij}\right)_L = 0.$$

Comparison with Hydrodynamics



Hydro works when $|X_1| > 3/\pi T \text{ and } X_p > 1/\pi T$

Results do not change with increasing t'Hooft coupling!

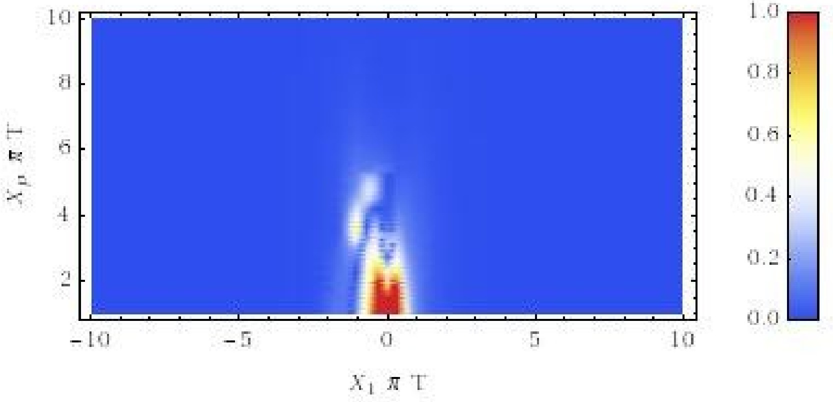
Comparison with Hydrodynamics

Hydro works when $|X_1| > 3/\pi T \text{ and } X_p > 1/\pi T$

Are the nonlinear terms in $\Pi_{\mu\nu}$ relevant in this description?

We compare the full numerical solution $\vec{U}$

with linearized (leading order in Nc) ansatz $\vec{U} \to -\frac{T^Y_{0i}}{4P_0}$



Conclusions & Outlook

- Linearized first-order NS provides accurate description of quark's wake down to distances $\geq 3/\pi T$.

- Thermalization scale compatible with v2 measurements.

- Repeat analysis including second-order hydrodynamic corrections.

- Compute subleading 1/Nc corrections.

Backup

AdS/CFT Duality

N=4 SYM plasma in D=4 ~ Type IIB string theory in $AdS_5 \otimes S_5$

$$\lambda \equiv g_{SYM}^2 N_c = \frac{L^4}{l_s^4}$$

$$g_{SYM} \to 0 \quad , N_c \to \infty \Longrightarrow \lambda \gg 1$$

$$g_{SYM}^2 = 4\pi g_s$$

AdS/CFT Duality

Drag force of N=4 SYM plasma

$$\frac{dp}{dt} = -\frac{\pi\sqrt{g_{\mathrm{YM}}^2 N}}{2} T^2 \frac{v}{\sqrt{1-v^2}},$$

C. P. Herzog et al., JHEP 0607, 013 (2006); S. Gubser, PRD 74, 126005 (2006);
J. J. Friess et al., PRD 75, 106003 (2007).