AdS/CFT and applications

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Outline

Why use AdS/CFT?

The AdS/CFT description of a plasma system

A heavy-ion collision

Five AdS/CFT studies

Summary

The AdS/CFT correspondence

$\boxed{\mathcal{N} = 4 \text{ Super Yang-Mills theory}}$	$\equiv$	$\boxed{\text{Superstrings on } AdS_5 \times S^5}$
strong coupling		(semi-)classical strings
nonperturbative physics		or supergravity
very difficult		'easy'
weak coupling		highly quantum regime
'easy'		very difficult

- New ways of looking at nonperturbative gauge theory physics...
- Intricate links with General Relativity...
- Has been extended to many other cases

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$\mathcal{N} = 4$ plasma versus QCD plasma

Similarities:

- Deconfined phase
- Strongly coupled
- No supersymmetry!

Differences:

- No running coupling $\longrightarrow$ Even at very high energy densities the coupling remains strong
- (Exactly) conformal equation of state $\longrightarrow$ Perhaps not so bad around $T \sim 1.5 - 2.5\, T_c$
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One can pass to more complicated AdS/CFT setups and lift the above differences

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- The applicability of using $\mathcal{N} = 4$ plasma to model real world phenomenae dependes on the questions asked..
- Use it as a theoretical laboratory where we may compute from 'first principles' nonequilibrium nonperturbative dynamics
- Gain qualitative insight into the physics which is very difficult to access using other methods
- Discover some universal properties? (like η/s)

- For $\mathcal{N} = 4$ plasma the AdS/CFT correspondence is technically simplest
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The AdS/CFT description

Aim: Describe the time dependent evolving strongly coupled plasma system

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Describe it in terms of lightest degrees of freedom on the AdS side which are relevant at strong coupling

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$$ds^2 = \frac{g_{\mu\nu}(x^\rho, z)dx^\mu dx^\nu + dz^2}{z^2} \equiv g^{5D}_{\alpha\beta} dx^\alpha dx^\beta$$

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Compute the time-evolution by solving (numerically) 5D Einstein's equations

$$R_{\alpha\beta} - \frac{1}{2} g^{5D}_{\alpha\beta} R - 6\, g^{5D}_{\alpha\beta} = 0$$

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Extract physical observables (like $\langle T^{\mu\nu}(x^\rho)\rangle$) from the numerical geometry

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What physics can we extract?

- Asymptotics of $g_{\mu\nu}(x^\rho, z)$ at $z \sim 0$ gives the energy-momentum tensor $T_{\mu\nu}(x^\rho)$ of the plasma system
- We can test whether $T_{\mu\nu}(x^\rho)$ is of a hydrodynamic form...
- We can check for local thermal equilibrium

- The area of the apparent horizon defines for us the entropy density
- We observe some *initial entropy*

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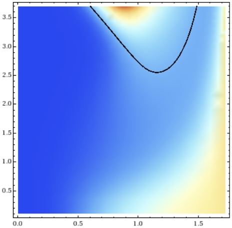

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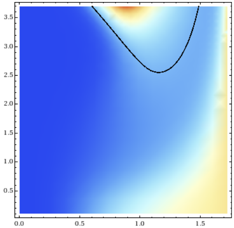

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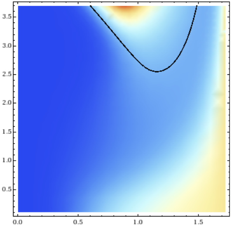

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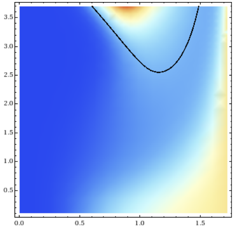

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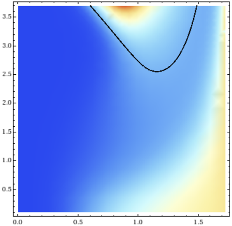

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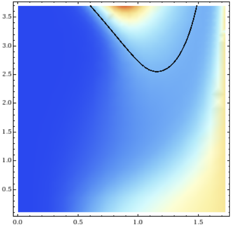

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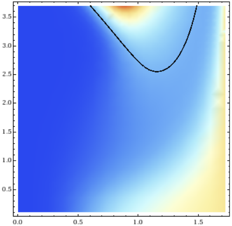

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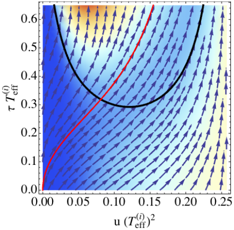

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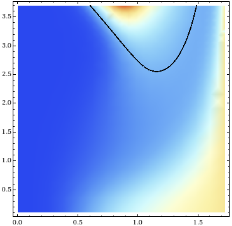

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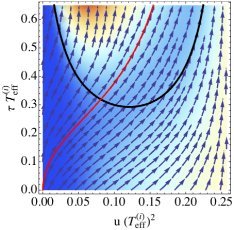

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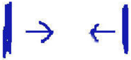

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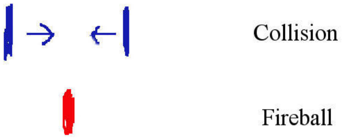

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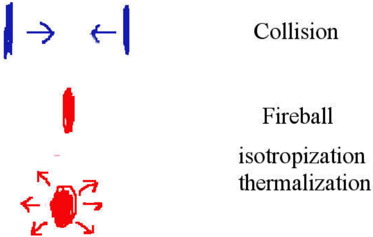

Collision

Fireball

isotropization
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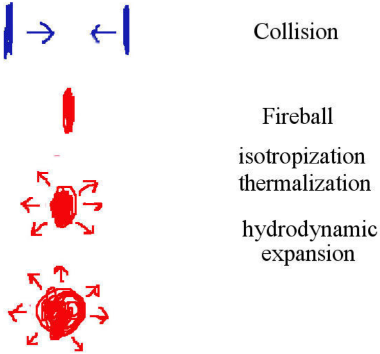

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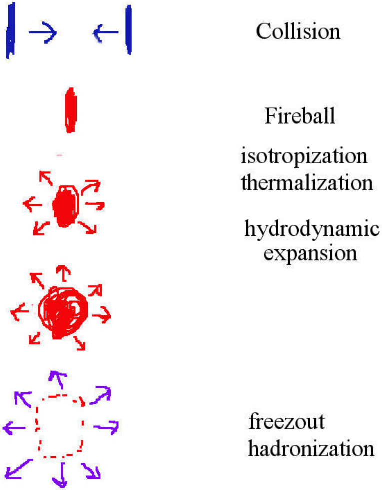

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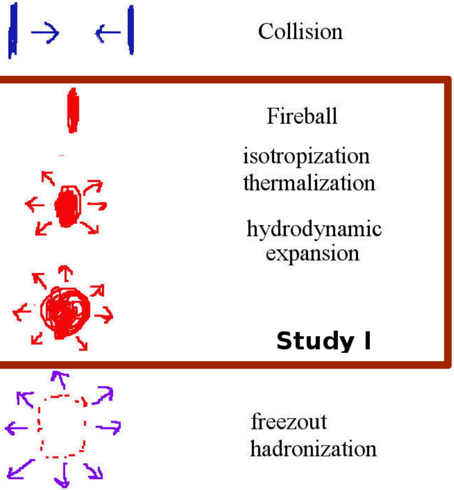

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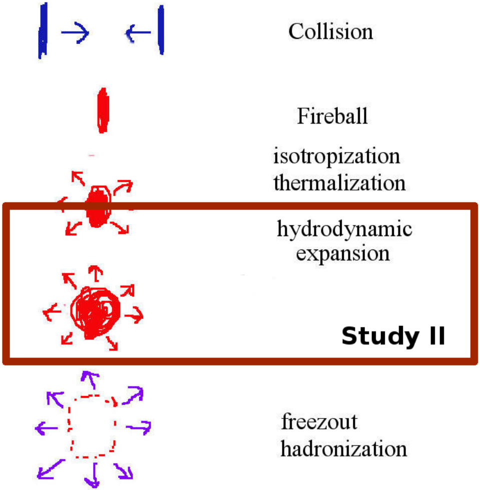

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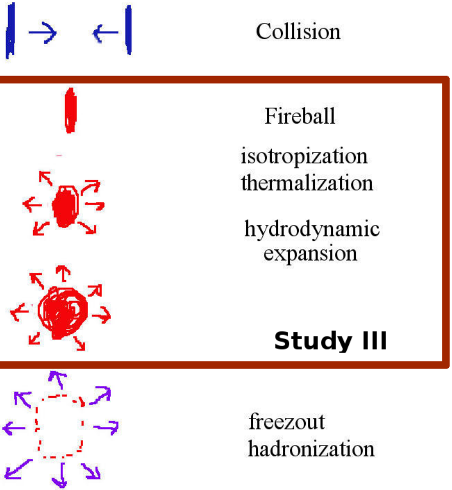

Collision

Fireball

isotropization
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Study III

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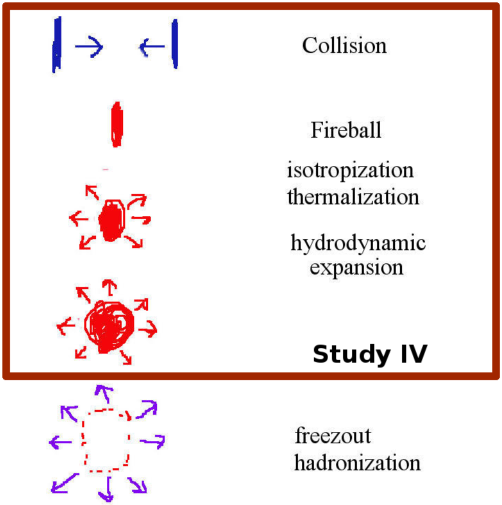

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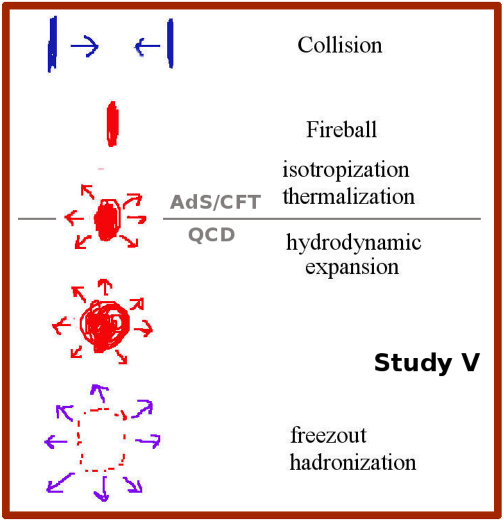

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Assume a flow that is invariant under longitudinal boosts and does not depend on the transverse coordinates.

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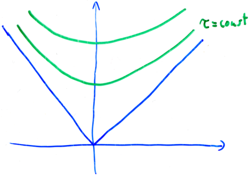

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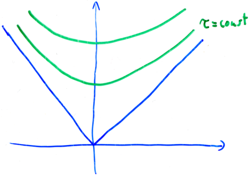

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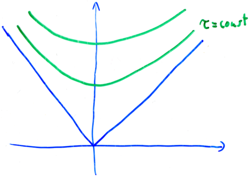

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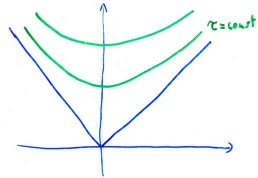

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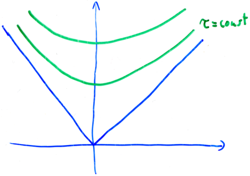

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2. Form the dimensionless product $w \equiv T_{eff} \cdot \tau$
3. For all initial conditions considered, *viscous* hydrodynamics works very well for $w \equiv T_{eff} \cdot \tau > 0.7$

   (natural values for RHIC: ($\tau_0 = 0.25\, fm$, $T_0 = 500\, MeV$) assumed in [Broniowski, Chojnacki, Florkowski, Kisiel] correspond to $w = 0.63$)
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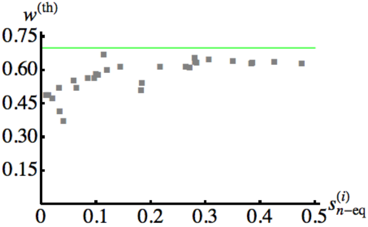

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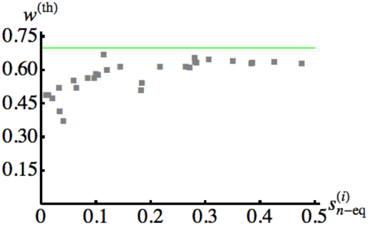

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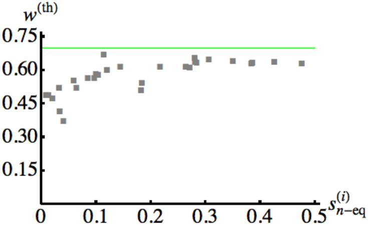

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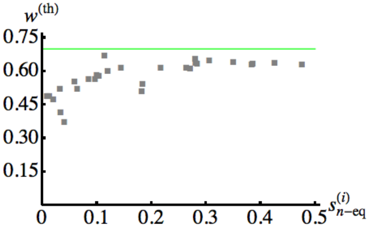

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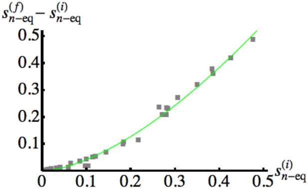

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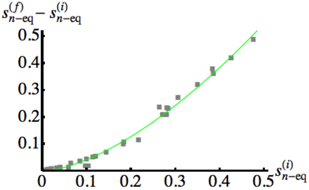

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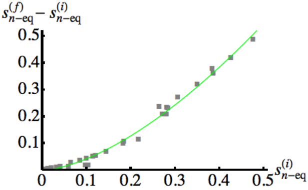

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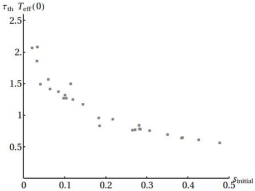

Study II Behaviour of high order dissipative hydrodynamics

M. Heller, RJ, P. Witaszczyk, 1302.0697 [PRL 110, 211602 (2013)]

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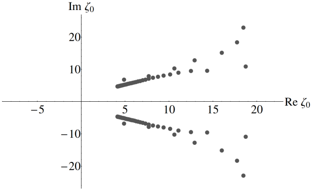

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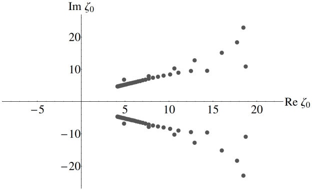

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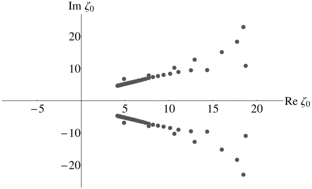

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What projectiles to use in $\mathcal{N} = 4$ SYM?

- RJ, Peschanski suggested to use planar shockwaves

$$T_{--} = \mu\,\delta(x^-) \quad \left(\text{or} \quad T_{--} = f(x^-) \right)$$

- Explicit and simple gravity dual
  various analytical explorations: Grumiller, Romatschke; Kovchegov, Taliotis
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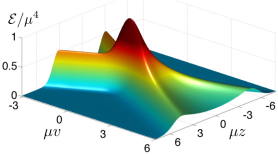

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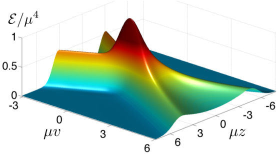

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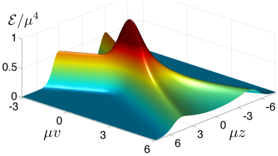

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Study IV Thick and thin shock-wave collisions

J. Casalderrey-Solana, M.P. Heller, D. Mateos, W. v.d. Schee, 1305.4919

talk by M.P. Heller, this conference

1. The character of the collision significantly depends on the thickness of the shock-wave (width in x^- relative to energy per unit transverse area)

2. For thick shock-waves, full stopping is recovered
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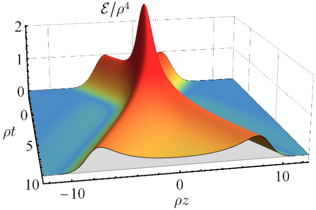

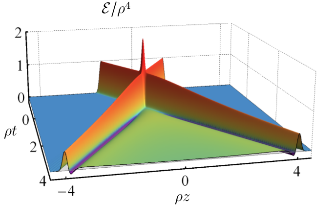

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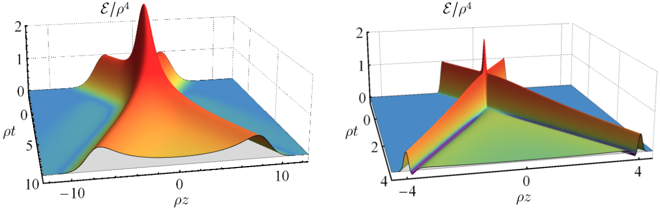

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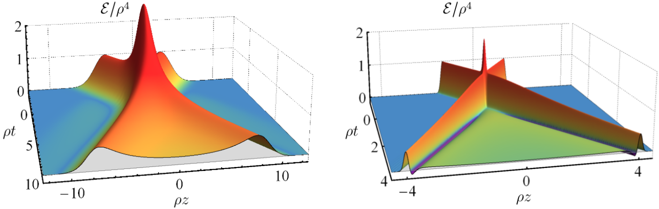

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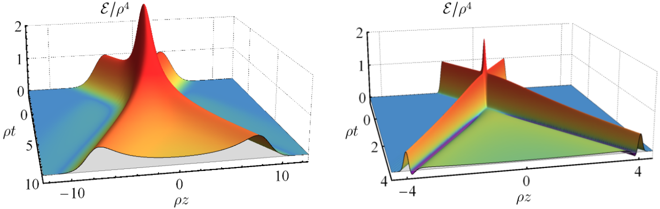

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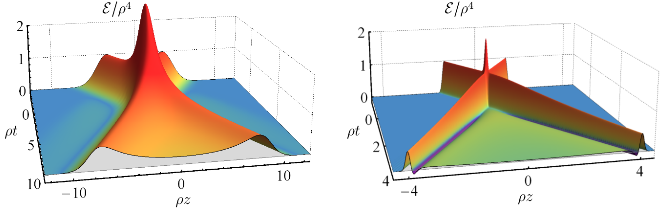

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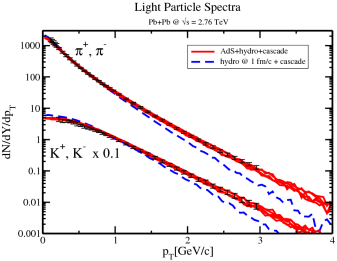

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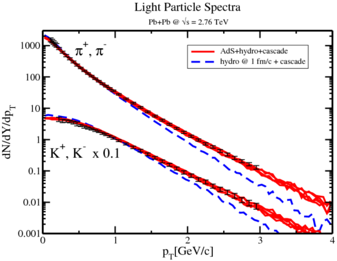

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