EoSization in non-conformal holographic shock wave collisions

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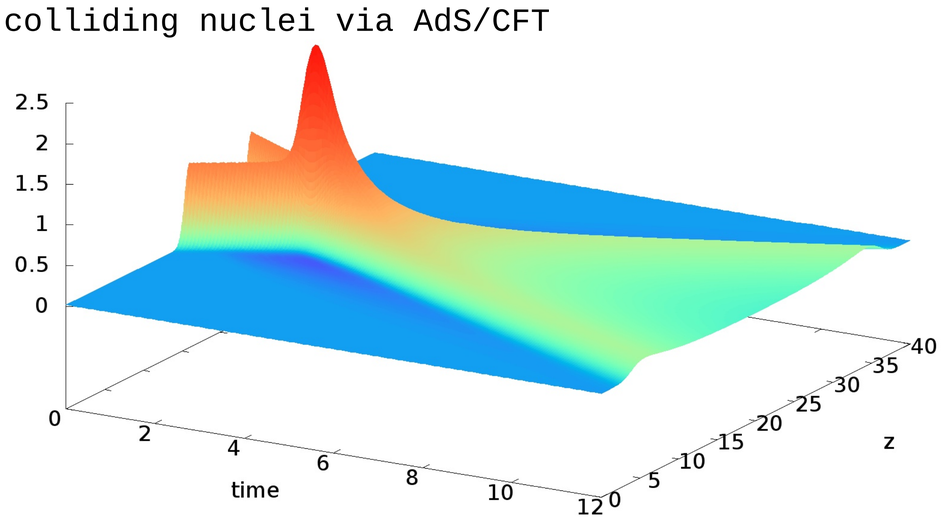
Introduction

The AdS/CFT correspondance builds a bridge between Quantum world problems and methods from General Relativity.

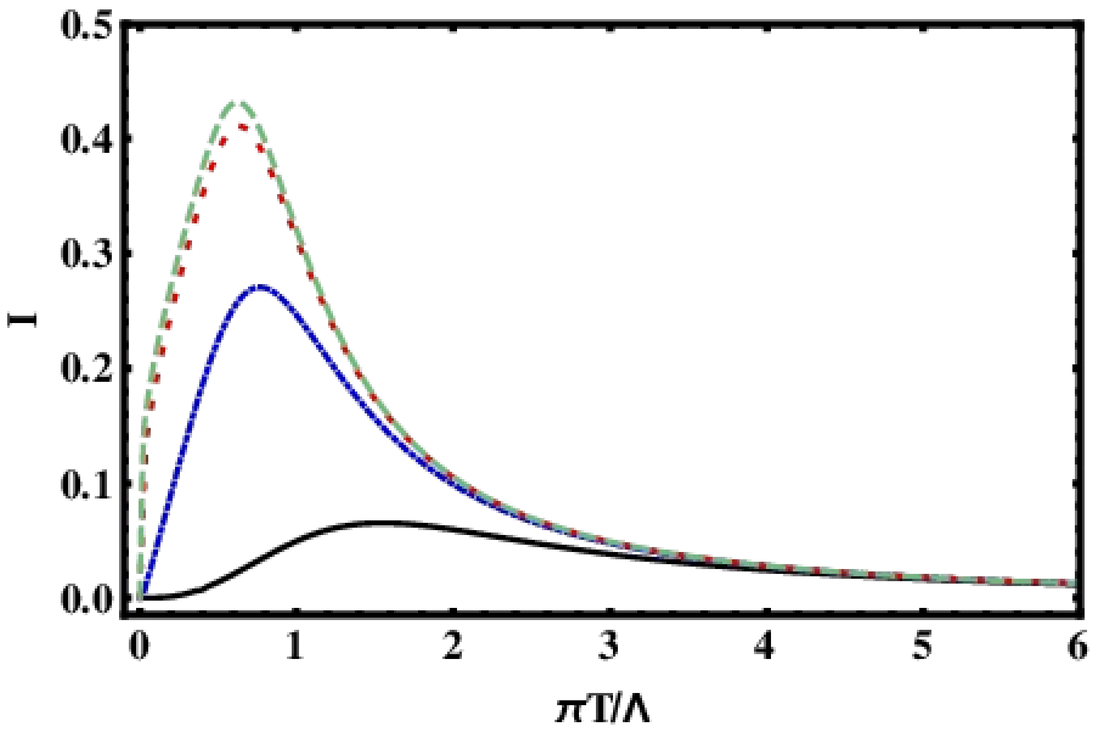
Holography allows to explore far from equilibrium dynamics:
- at strong coupling
- non-perturbatively
- in almost ideal fluids
- with fast hydrodynamization time
- as initial condition for hydrodynamics

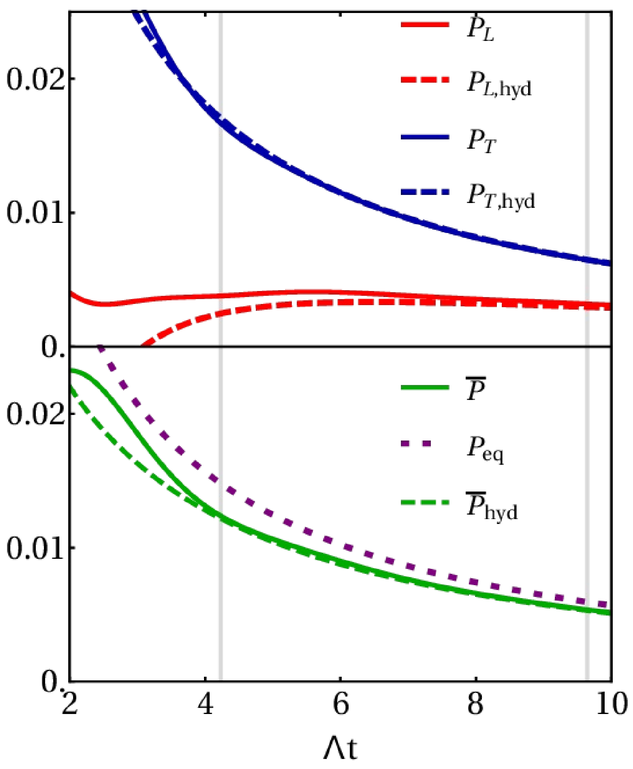
1) Hydrodynamization and EoSization in non-conformal theories By Maximilian Attems, Jorge Casalderrey-Solana, David Mateos, Daniel Santos-Oliván, Carlos F. Sopuerta, Miquel Triana, Miguel Zilhão. arXiv:1702.xxxxx [hep-th].
2) Holographic collisions in non-conformal theories By Maximilian Attems, Jorge Casalderrey-Solana, David Mateos, Daniel Santos-Oliván, Carlos F. Sopuerta, Miquel Triana, Miguel Zilhão. arXiv:1604.06439 [hep-th]. JHEP 1701 (2017) 026.
3) Thermodynamics, transport and relaxation in non-conformal theories By Maximilian Attems, Jorge Casalderrey-Solana, David Mateos, Ioannis Papadimitriou, Daniel Santos-Oliván, Carlos F. Sopuerta, Miquel Triana, Miguel Zilhão. arXiv:1603.01254 [hep-th]. JHEP 1610 (2016) 155.

Energy density of colliding shock waves dual to colliding nuclei via AdS/CFT



Temperature dependent non-conformality interaction measure: I = (E-3P) for non-conformal theories





EoSization & Hydrodynamization

EoSization:

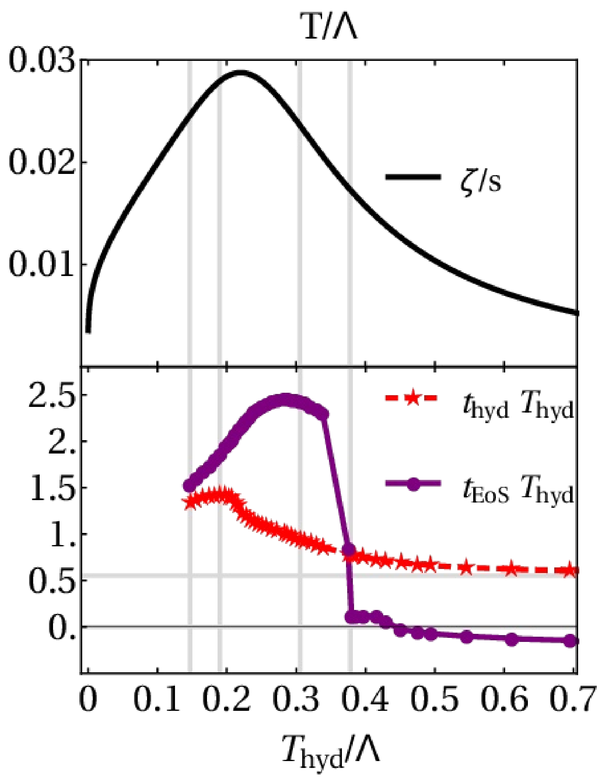
$$\left|\bar{P} - P_{\mathrm{eq}}\right| / \bar{P} < 0.1$$

Hydrodynamization:

$$\left|P_{L,T} - P^{\mathrm{hyd}}_{L,T}\right| / \bar{P} < 0.1$$

At Hydrodynamization time t_{hyd} the average pressure $\bar{P}$ and the equlibrium pressure P_{eq} still differ by 17%, while $P_T \neq P_L$ even at EoSization time t_{EoS}.

See left panel for longitudinal P_L and transverse P_T pressures evolution.



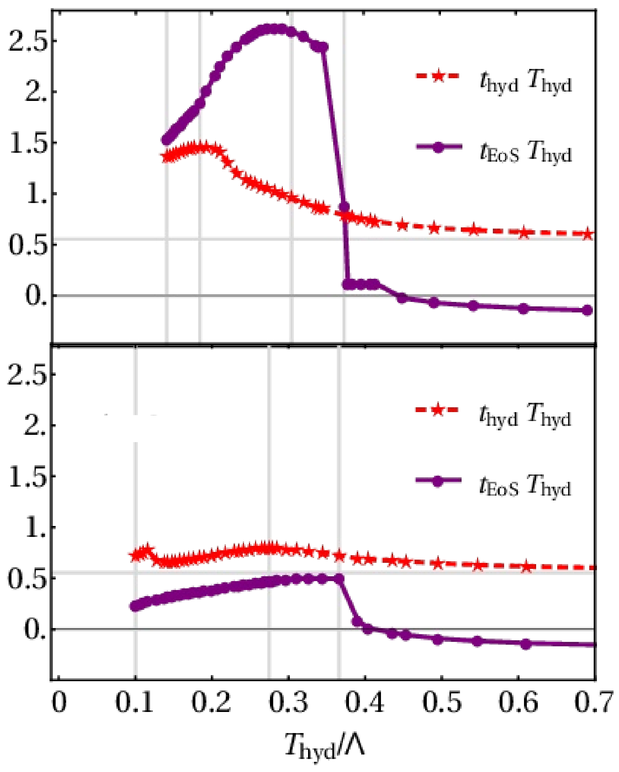
Non-conformal temperature scan I

Computing the EoSization and hydrodynamization time over different temperature one notices:

t_{hyd} (lower panel) increases with larger bulk viscosity ζ over entropy density s (upper panel).

The ordering of t_{EoS} and t_{hyd} depends on bulk viscosity.

$t_{EoS} > t_{hyd}$ requires ζ bulk viscosity over s entropy density $\zeta/s \gtrsim 0.025$.



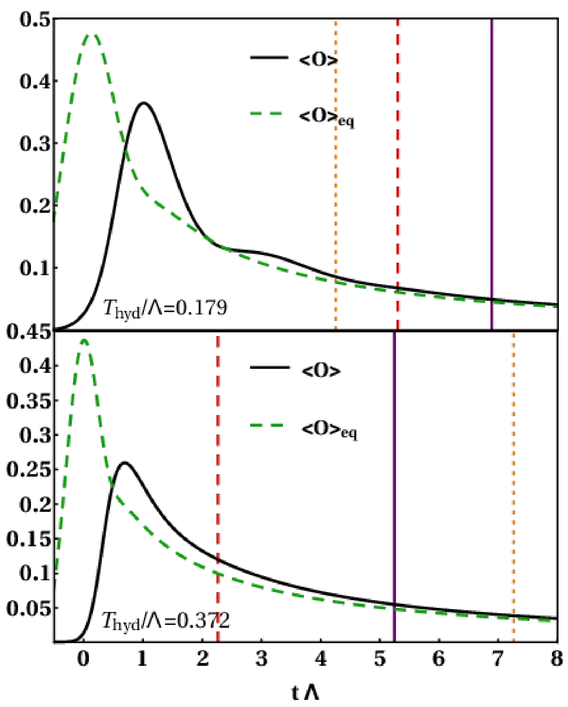
Non-conformal temperature scan II

Comparison of theories with large (upper panel) and small (lower panel) non-conformality.

In the upper panel one sees a wide temperature range of non-conformality with $t_{\mathrm{EoS}} \geq t_{\mathrm{hyd}}$.

In the lower panel the bulk viscosity is not sufficient to have an EoSization after hydrodynamization.

Zero or negative EoSization time equals to an almost conformal run.



Scalar condensate

Deforming the gauge theory with a dimension 3 operator $\mathcal{O}$ dual to the scalar field. $< O >$ aquires an expectation value.

Scalar relaxation:

$$\left|\bar{O} - O_{\mathrm{eq}}\right| / O < 0.1$$

On the left are shown the evolution of $< O >$ which relaxes before (upper panel) and after (lower panel) the Hydrodynamization and EoSization times.

Summary

First simulation of a holographic non-conformal model for heavy ion collisions

Hydrodynamization $\neq$ EoSization $\neq$ Isotropization $\neq$ Scalar relaxation

Hydrodynamics works early
- still very fast for both RHIC and LHC
- despite non-trivial equation of state
- despite significant ζ/s bulk over entropy

Conservative estimate $\zeta/s \approx 0.025$ for non-conformality