Title: Collisions in AdS and the thermalisation of heavy-ion collisions

Date: Nov 28, 2013 01:00 PM

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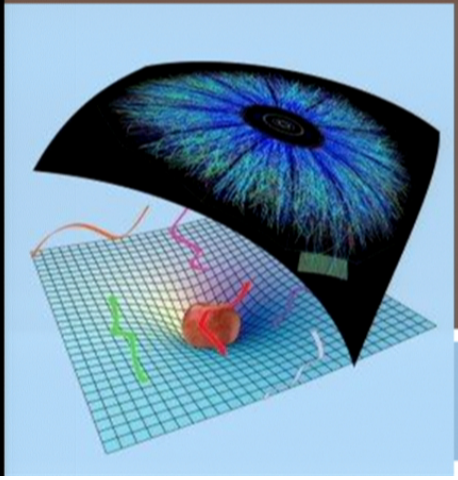
Abstract: The motivation of this seminar is to understand the thermalisation of heavy ion collisions using AdS/CFT. These collisions can be modelled as colliding planar gravitational shock waves. This gives rise to rich and interesting dynamics; wide shocks come to a full stop and expand hydrodynamically, as was previously found by Chesler and Yaffe. High energy collisions (corresponding to thin shocks) pass through each other, after which a plasma forms in the middle, within a proper time 1/T, with T the local temperature at that time. After this I will discuss recent results where we studied the influence of microscopic structure in the longitudinal direction of the shock waves, and thereby found a coherent regime. This has implications for both fluctuations in nucleus-nucleus collisions, and for recent proton-lead collisions at at LHC. The final part will cover a radially expanding calculation, where some simplifications allowed us to solve the model all the way till the final particle spectra, with an interesting comparison with experimental data.

COLLISIONS IN ADS AND THE THERMALISATION OF HEAVY IONS

Towards more realistic models of the QGP thermalisation

Work with Michał Heller, David Mateos, Jorge Casalderrey, Paul Romatschke and Scott Pratt
References: 1305.4919 (PRL 111), 1307.2539 (PRL 111), 1311.xxxx



Wilke van der Schee

Supervisors: Gleb Arutyunov,
Thomas Peitzmann and Raimond Snellings

Strong Gravity Seminar Perimeter
28 November, 2013

Outline

Wilke van der Schee, Utrecht

- Heavy-ion primer + motivation AdS/CFT
- Gravitational shock waves in AdS
  - Low/high energy behaviour: stopping/transparency
  - No boost-invariance
  - *New*: Influence of microstructure: a prediction for p-Pb
- An extension: boost-invariant radial flow
  - Hydrodynamics+cascade → spectra

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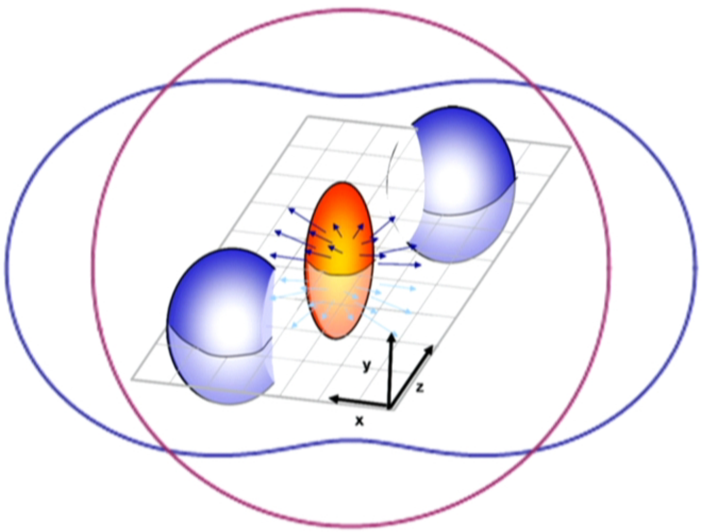
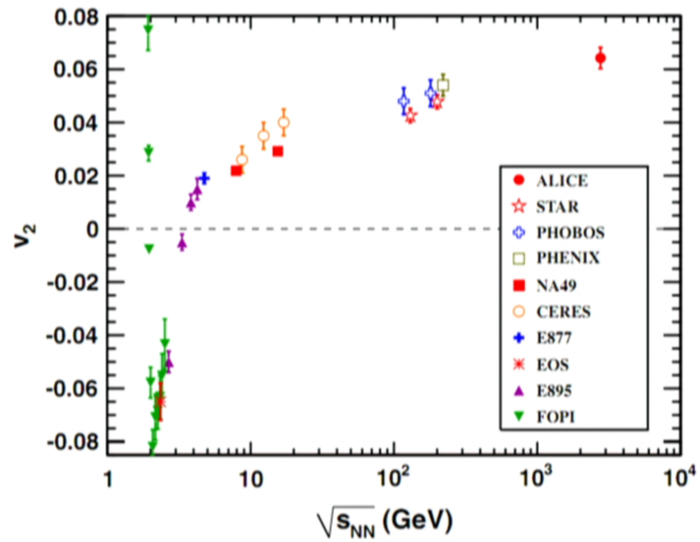
Elliptic flow: v_2, QGP is interesting

Wilke van der Schee, Utrecht

- How anisotropic is the final state?
  - Ideal gas/weak coupling
  - Perfect fluid/strong coupling





K. Aamodt et al, Elliptic Flow of Charged Particles in Pb-Pb Collisions at $\sqrt{s_{NN}}$=2.76 TeV (2010)

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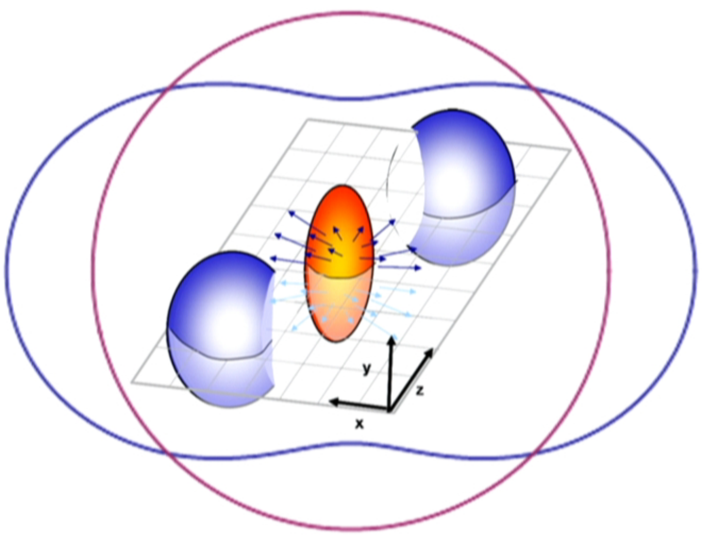

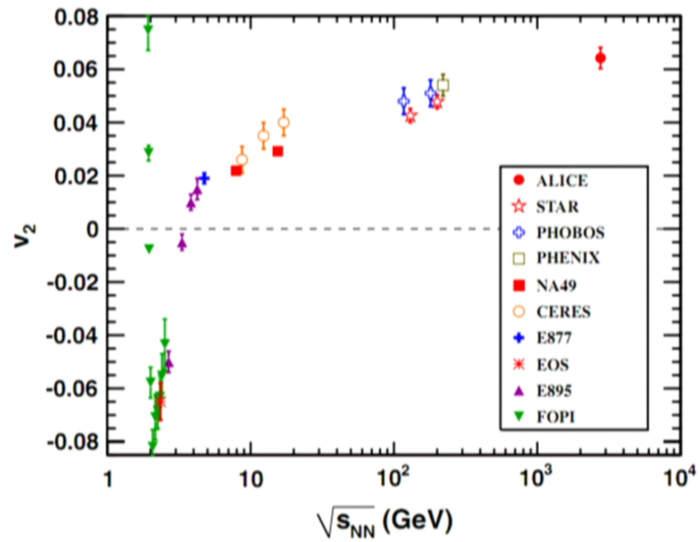

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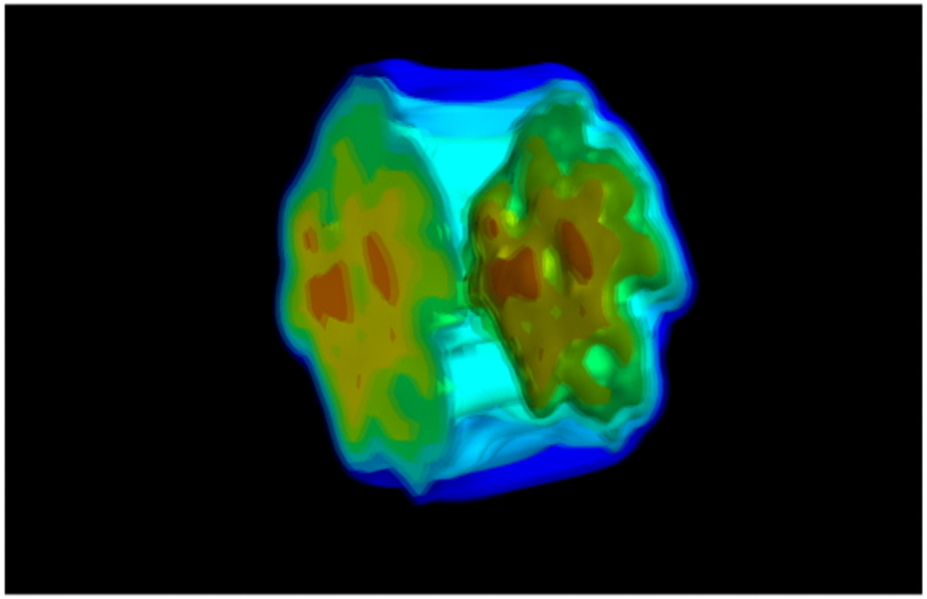
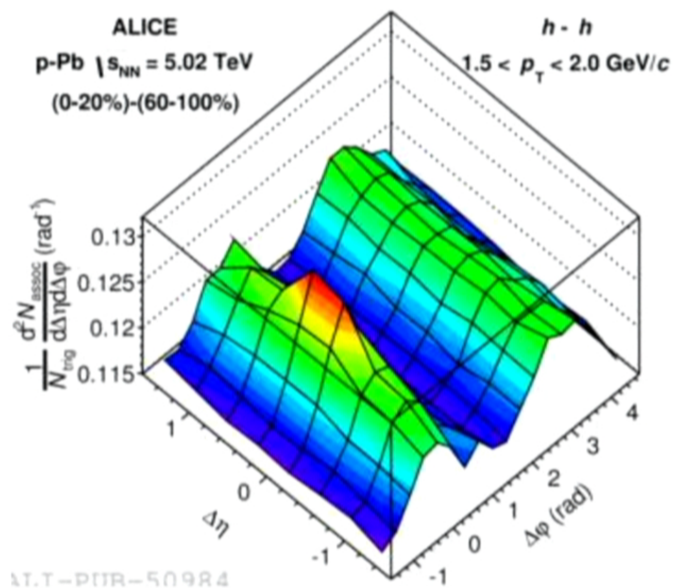
Heavy ion state-of-the-art (Bjorn Schenke)

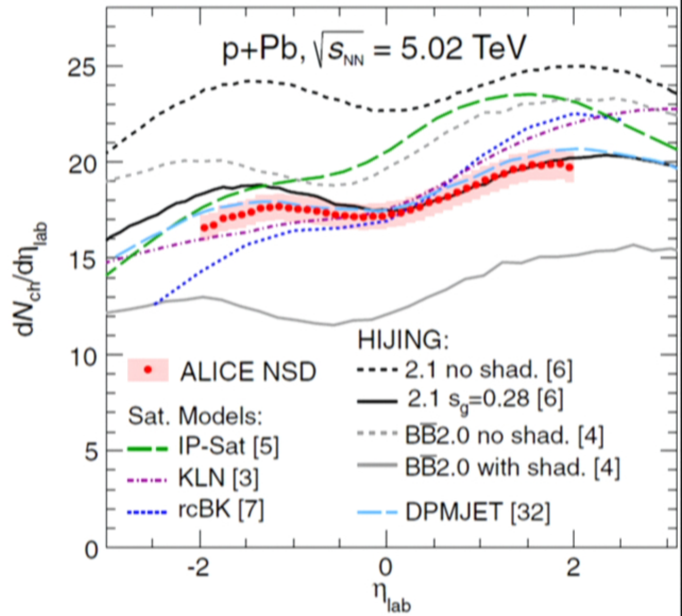
- Start with energy density from Wood-Saxon profile
  - Fluctuations may follow from glasma/saturation
  - Profile in rapidity largely put in by hand (BI+cut-off)



Heavy ions - recent excitement

- Double ridge observed in p-Pb
- Mass ordering of v_2 similar to hydro models





ALICE, Long-range angular correlations on the near and away side in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
ALICE, Pseudorapidity Density of Charged Particles in p-Pb Collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

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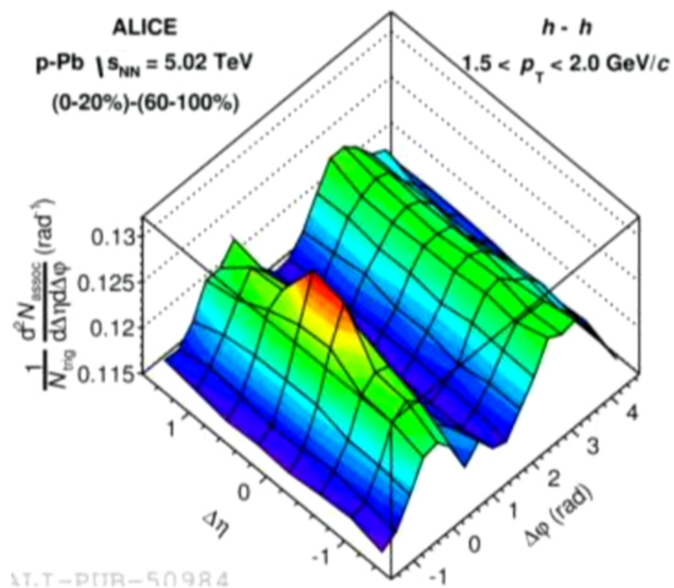

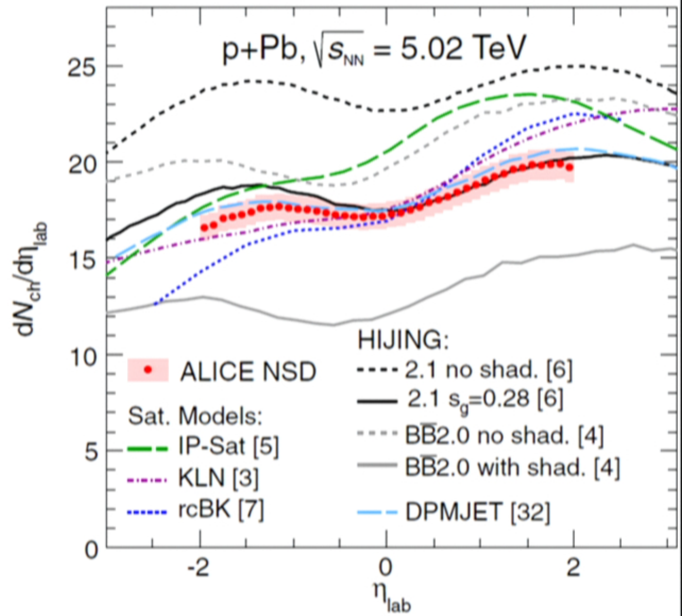

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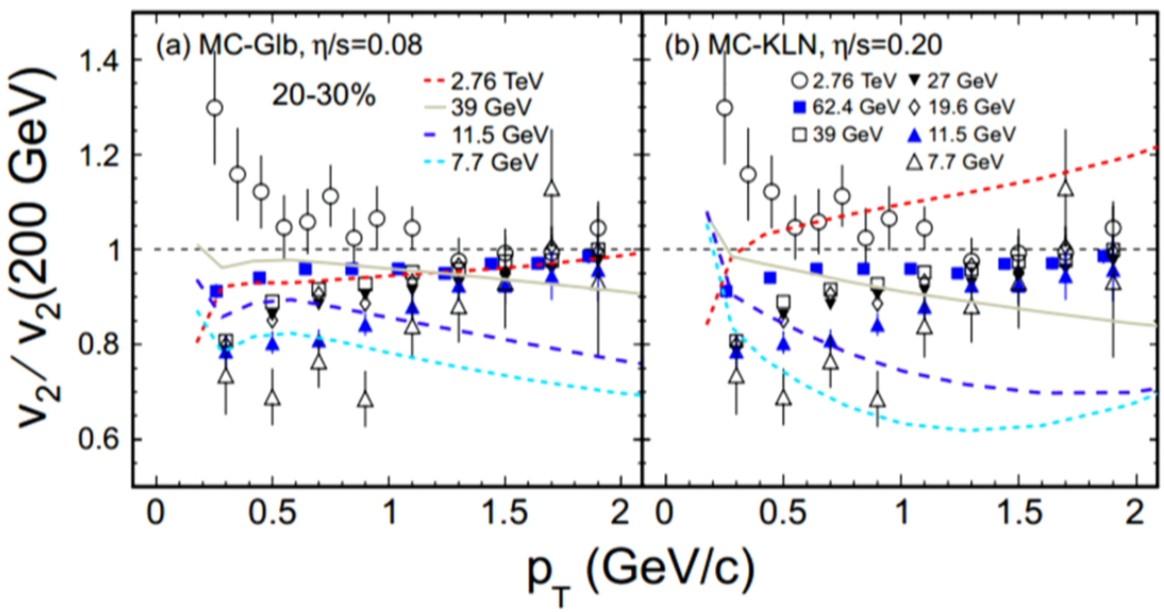
Heavy ions - recent excitement

Wilke van der Schee, Utrecht

- Extensive study at RHIC: problems with hydro
  - Very little dependence v_2 on collision energy



STAR collaboration, Inclusive charged hadron elliptic flow in Au + Au collisions at $\sqrt{s_{NN}}$ = 7.7 - 39 GeV (2012)

Elliptic flow: v_2, QGP is interesting

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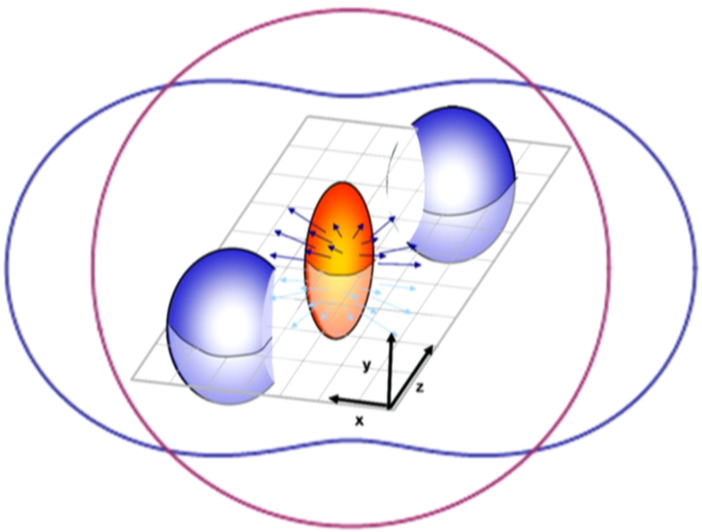

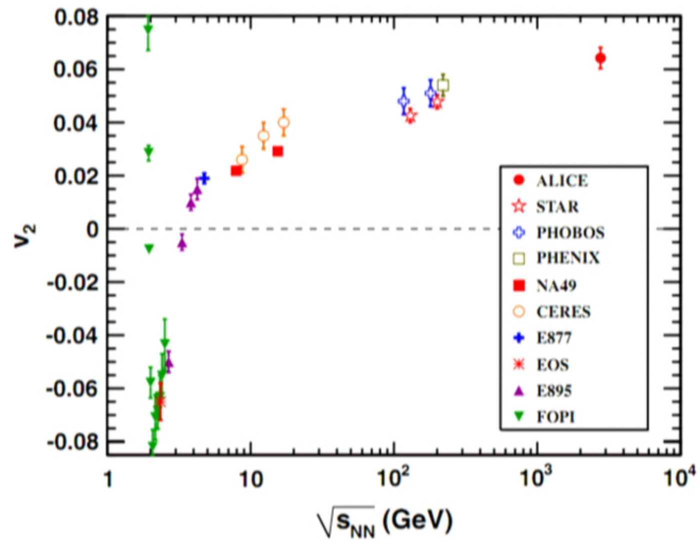

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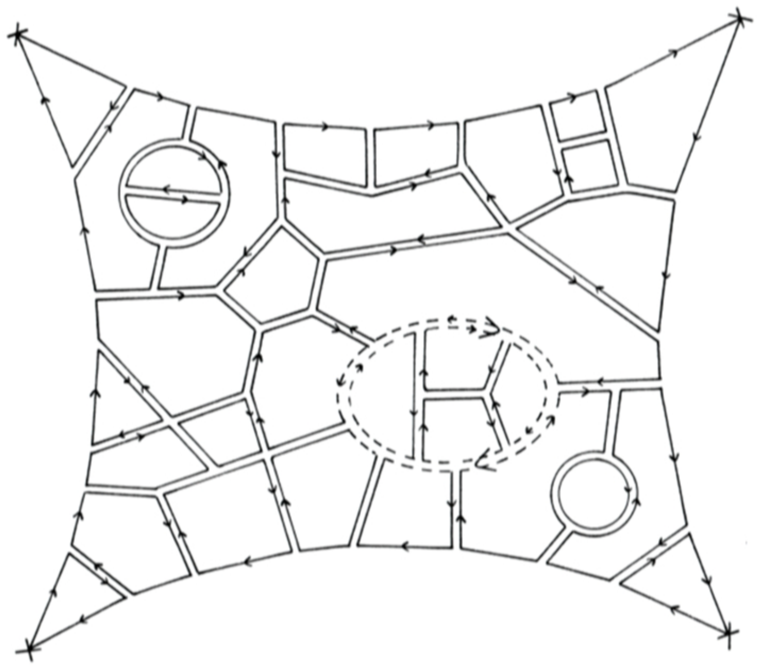
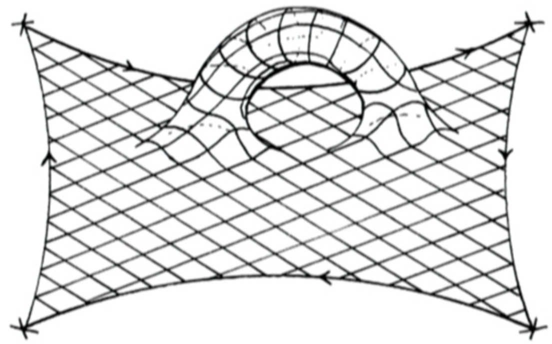
Large N gauge theories

- At strong coupling we can get GR





Planar limit:

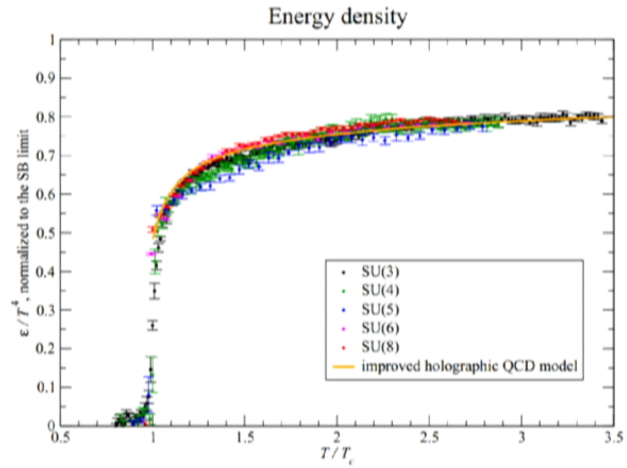
$\lambda = g^2 N$ fixed

$N \to \infty$

G. 't Hooft, A planar diagram theory for strong interactions (1974)

Are we perhaps not cheating with $\mathcal{N}$=4 SYM?

- SU(N): 3 ≈ ∞?
  - Good for thermal
- Quarks?
  - Replaced by (dominant) gluons
- Infinite coupling strength?
  - But coupling runs only logarithmicall



- Theories not the same:

$$\mathcal{E} = \frac{3N_c^2\pi^2}{8}T^4 \approx 33.3T^4(\mathcal{N}=4) \qquad \mathcal{E} \approx 11T^4(\mathrm{QCD})$$

- So maybe not too bad; and with room for improvement ☺

M. Panero, Thermodynamics of the QCD plasma and the large-N limit (2009)

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8/29

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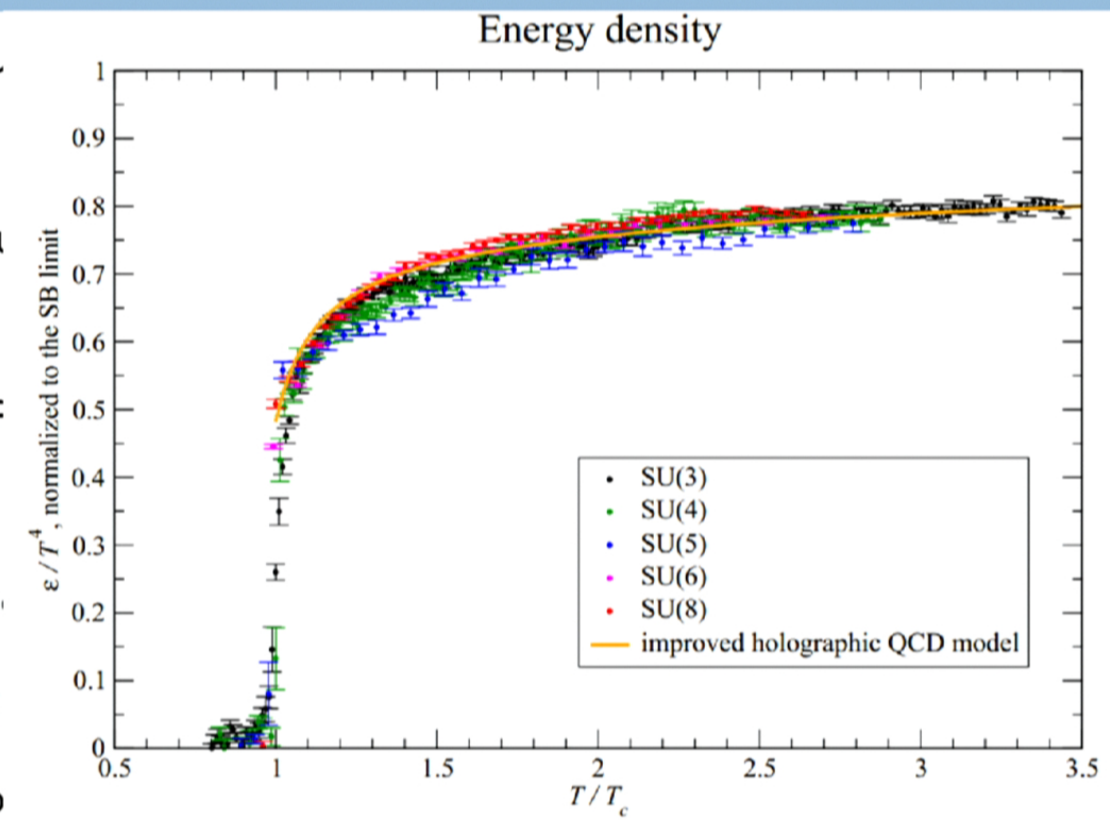

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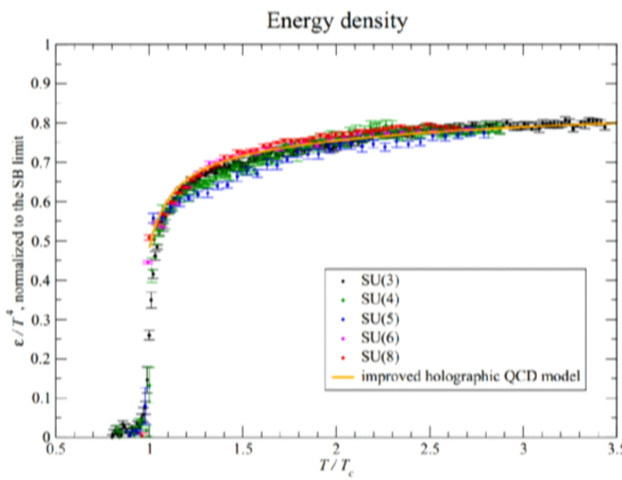

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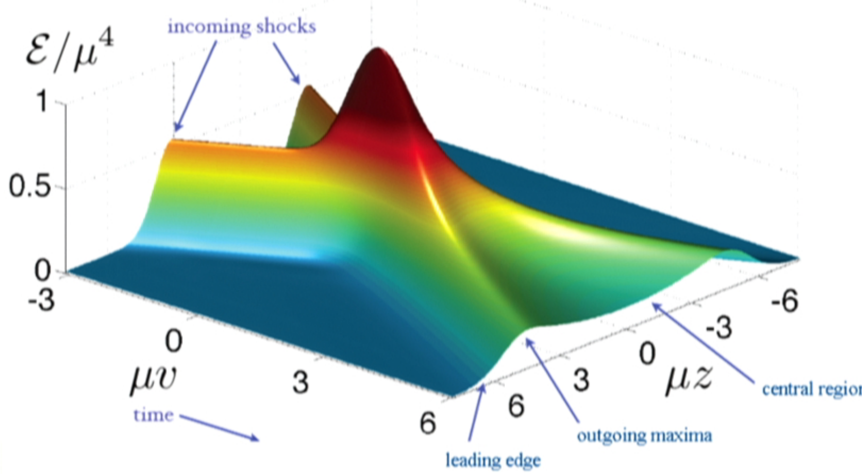
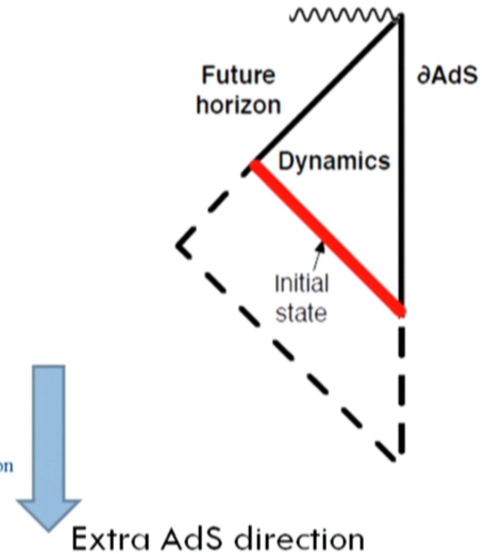
Shock waves – initial conditions

- Famous example:





- Homogeneous in transverse plane ('infinite nucleus')
- Energy density moving at speed of light: initial conditions fixed
  - Two scales: width + total energy
- Only gravity: dominant force at high energy

P.M. Chesler and L.G. Yaffe, Holography and colliding gravitational shock waves in asymptotically AdS_5 spacetime (2010)

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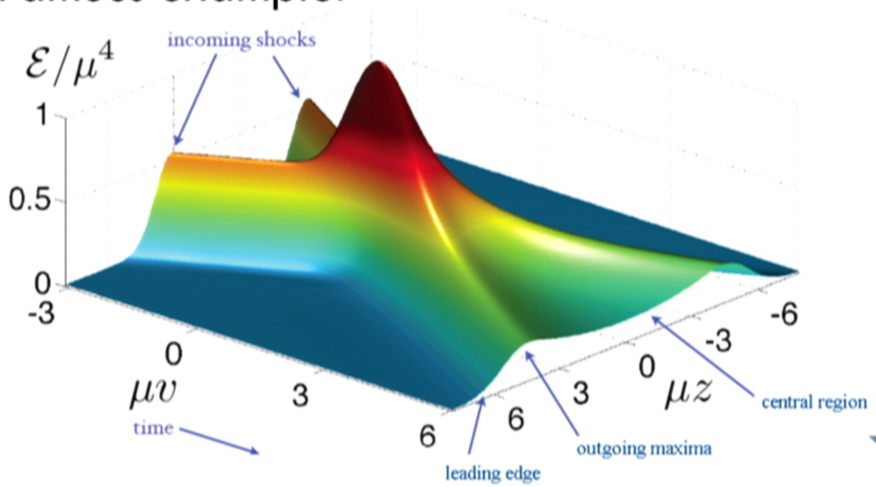

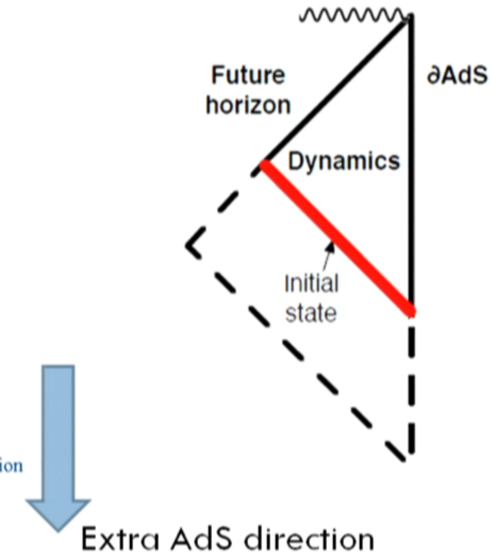

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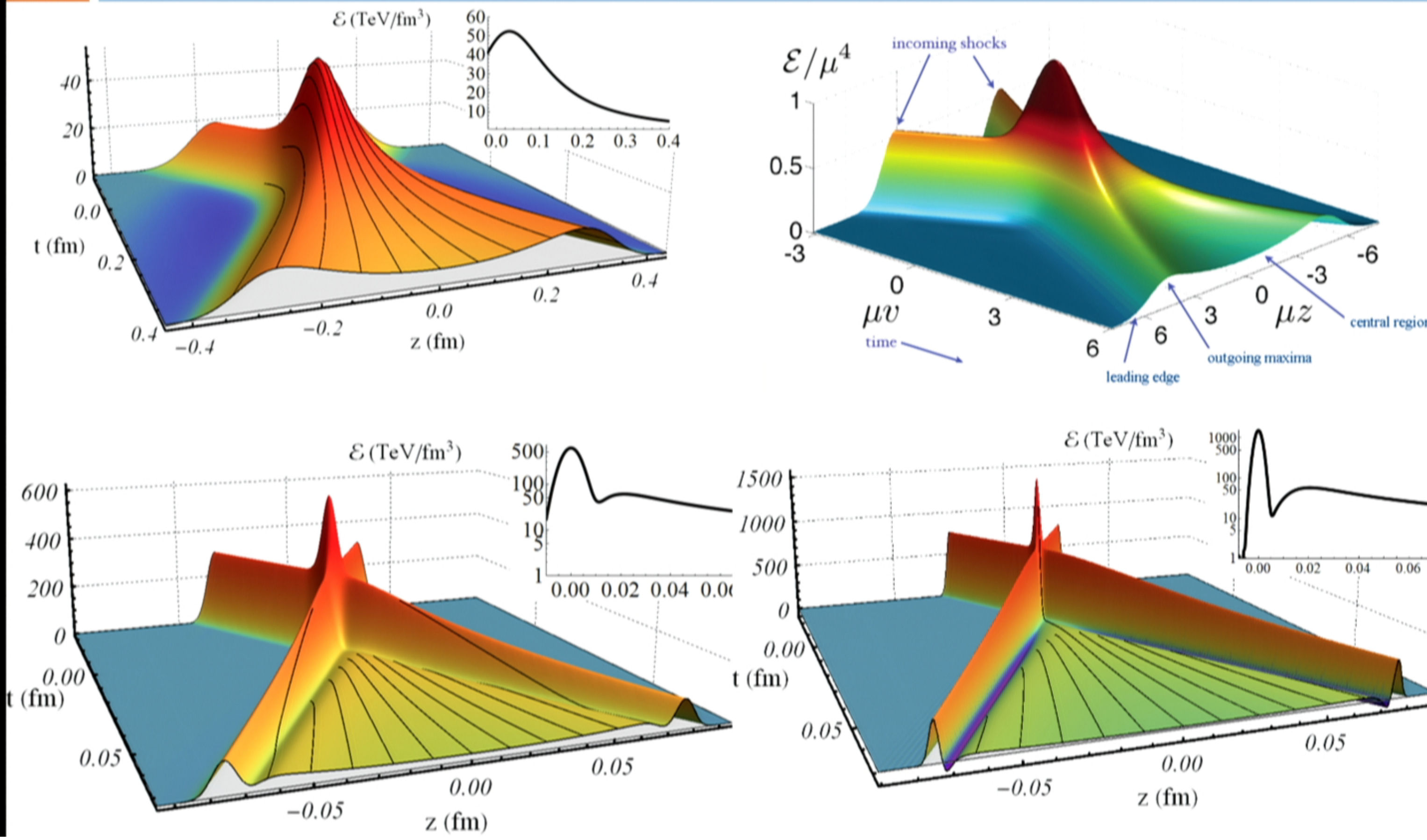

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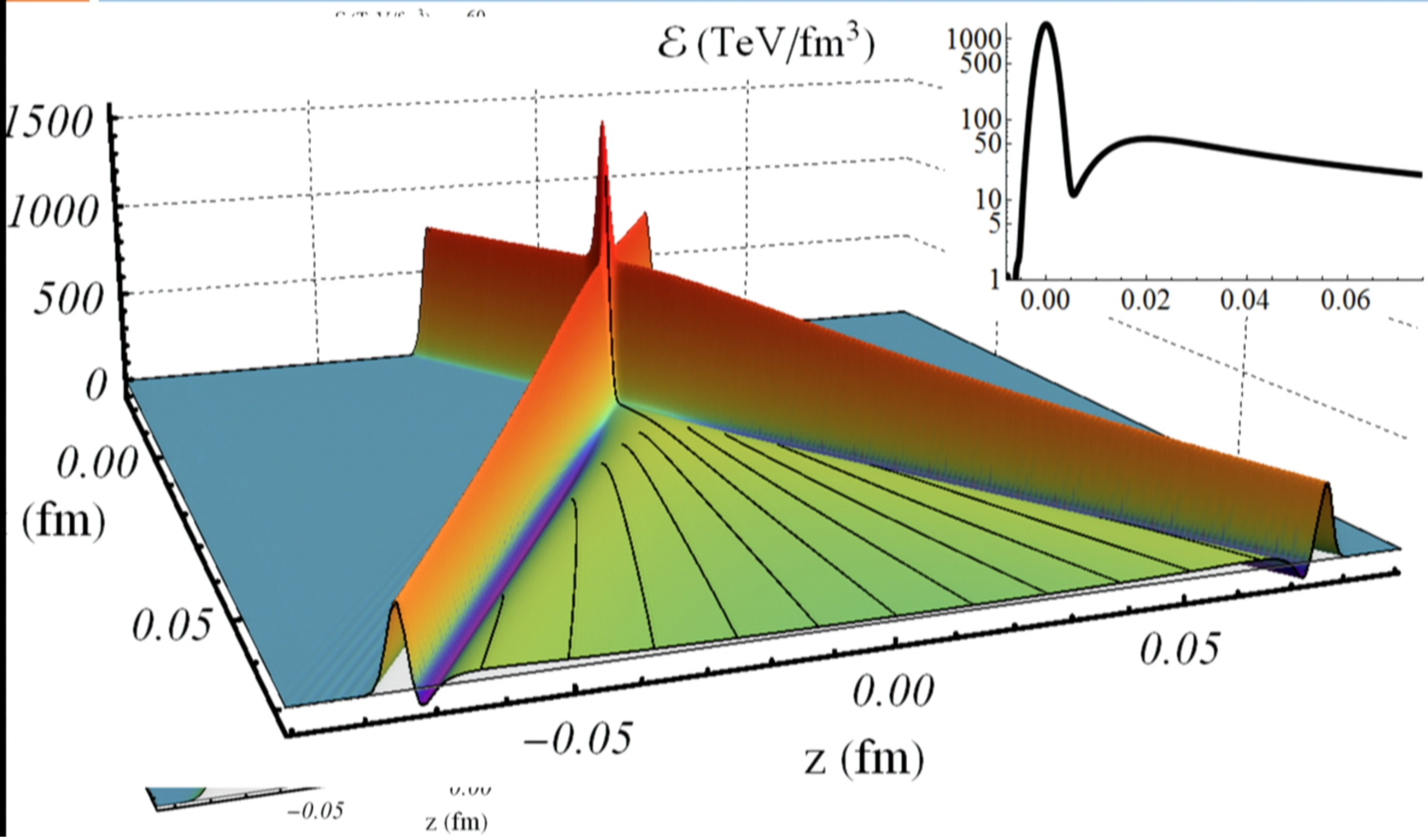
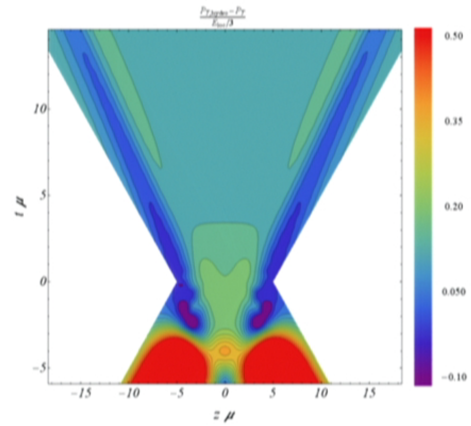
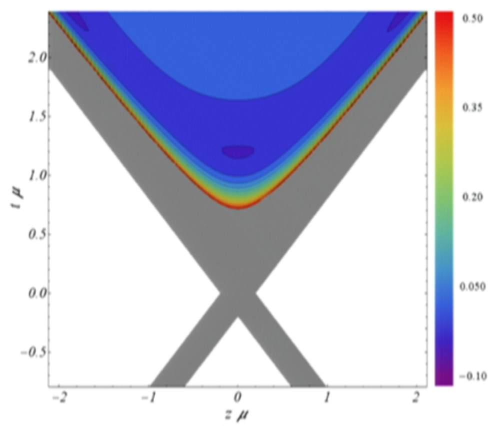


A dynamical cross-over

Wilke van der Schee, Utrecht

- Low energy:
  - Stopping, piling up of energy
  - Expansion by hydro
  - Compressed Landau model
- RHIC energy
  - Landau model
  - entropy $\sim (\sqrt{s_{NN}})^{1/2}$
- High energy:
  - no stopping
  - plasma forms slowly
  - transient negative energy
  - entropy $\sim (\sqrt{s_{NN}})^{2/3}$





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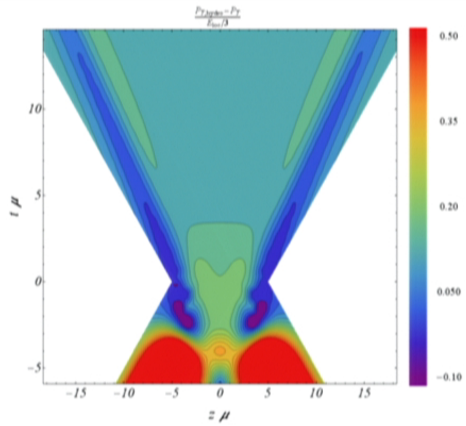

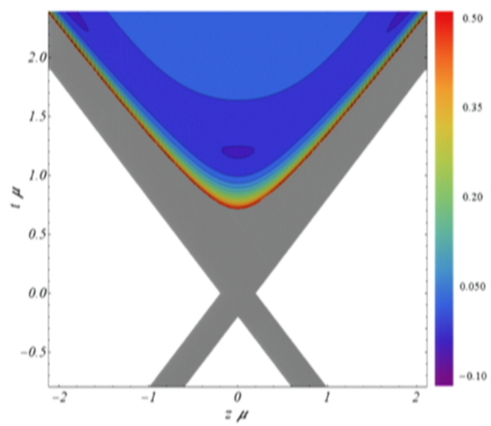

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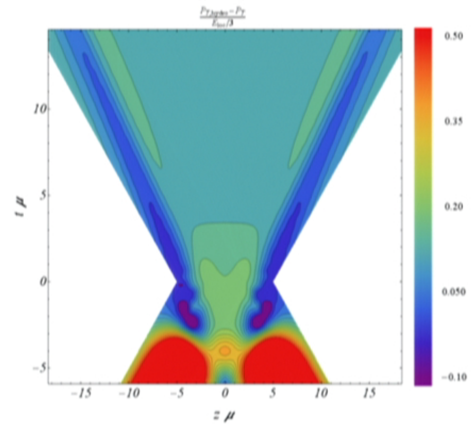

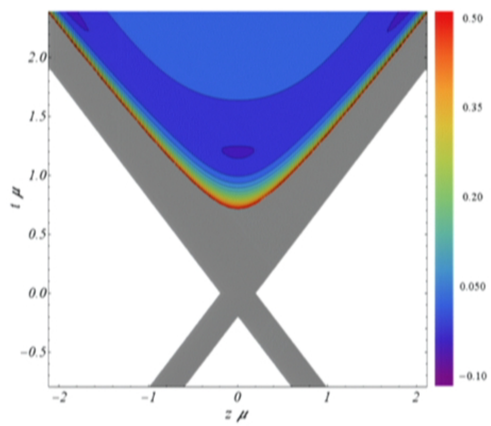

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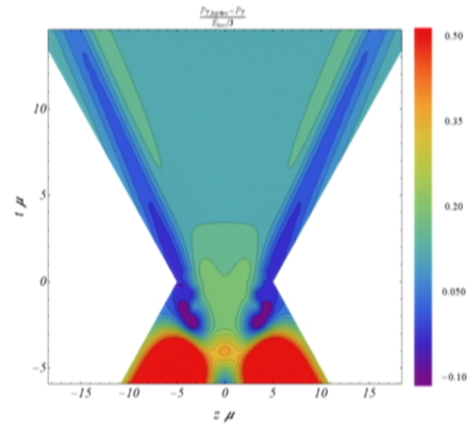

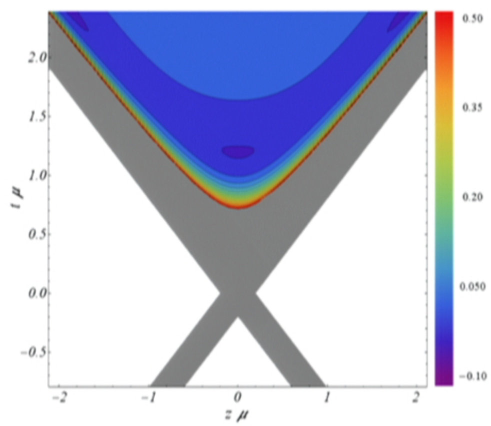

Shock waves – boost-invariance

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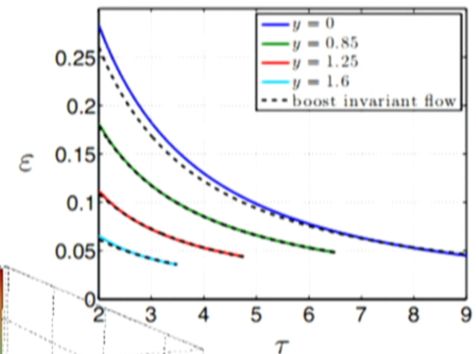
- No boost-invariance
  - Profile approx gaussian with slightly increasing width
  - However, time variation quite slow, see BI-fits (Chesler/Yaffe):



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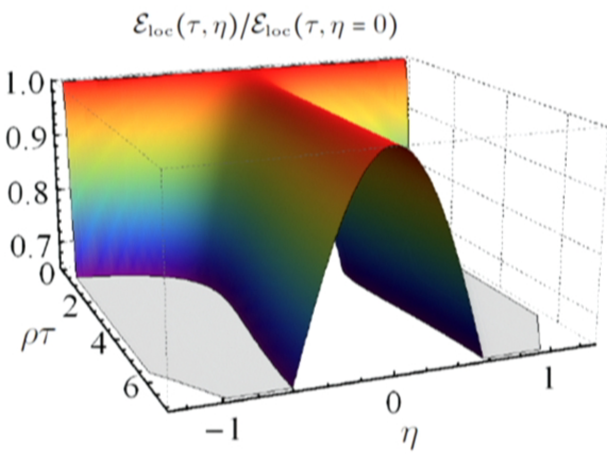
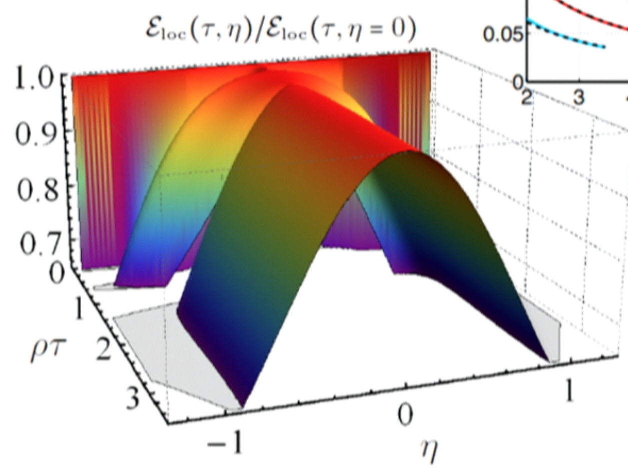


High energy:



Time evolution of rapidity profile

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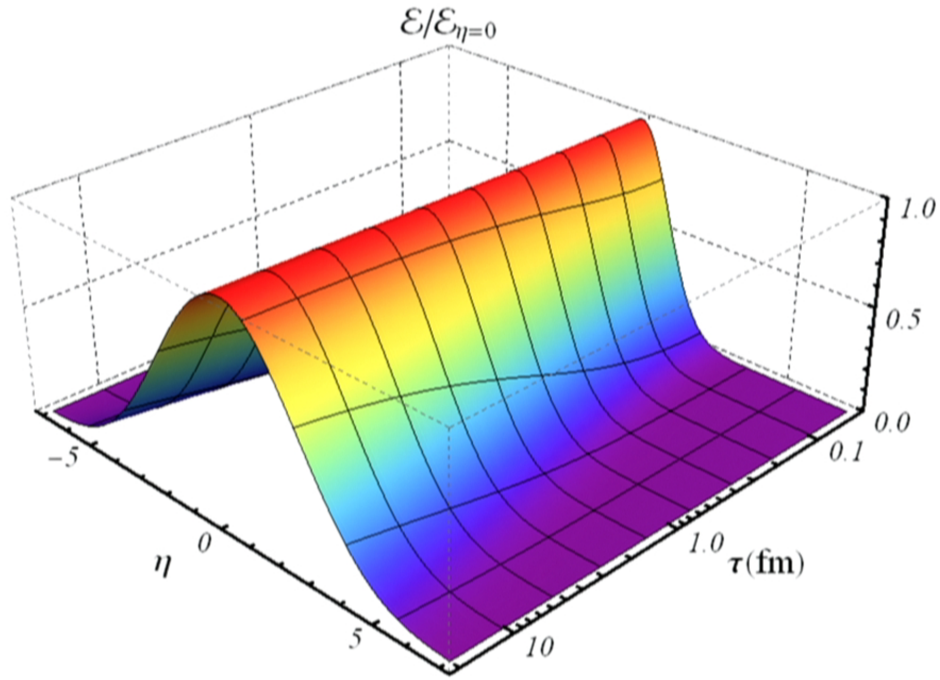
- Back-of-the-envelope:
  - Plug into EOM of ideal hydro



Shock waves from the bulk

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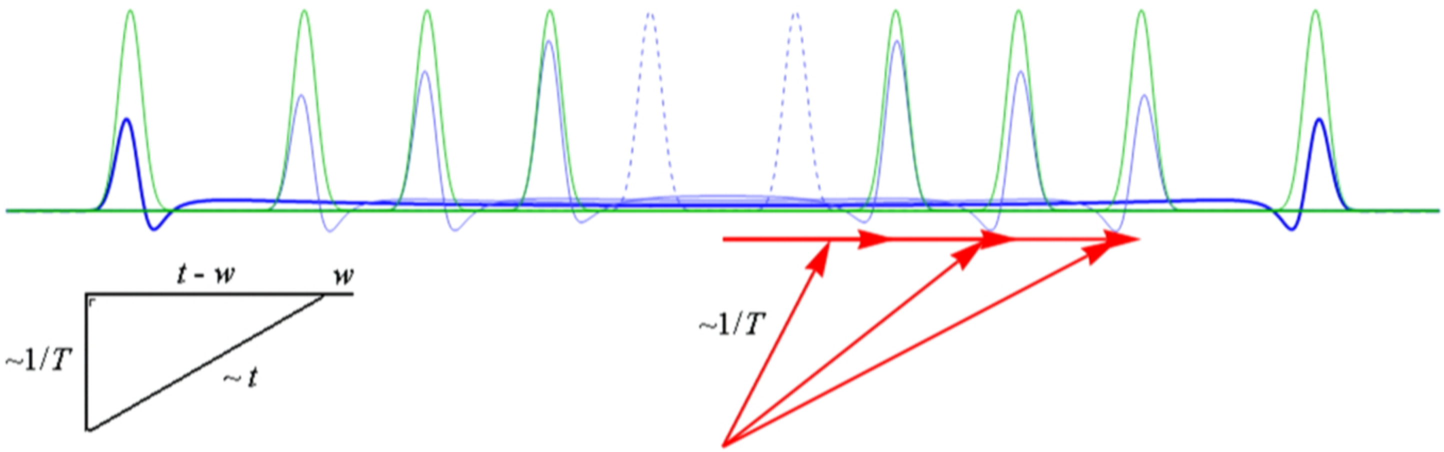
- Interesting interplay between temperature & width:
  - Non-linearity roughly comes from horizon
  - Touches front-end latest: by causality!



Newer results – longitudinal coherence

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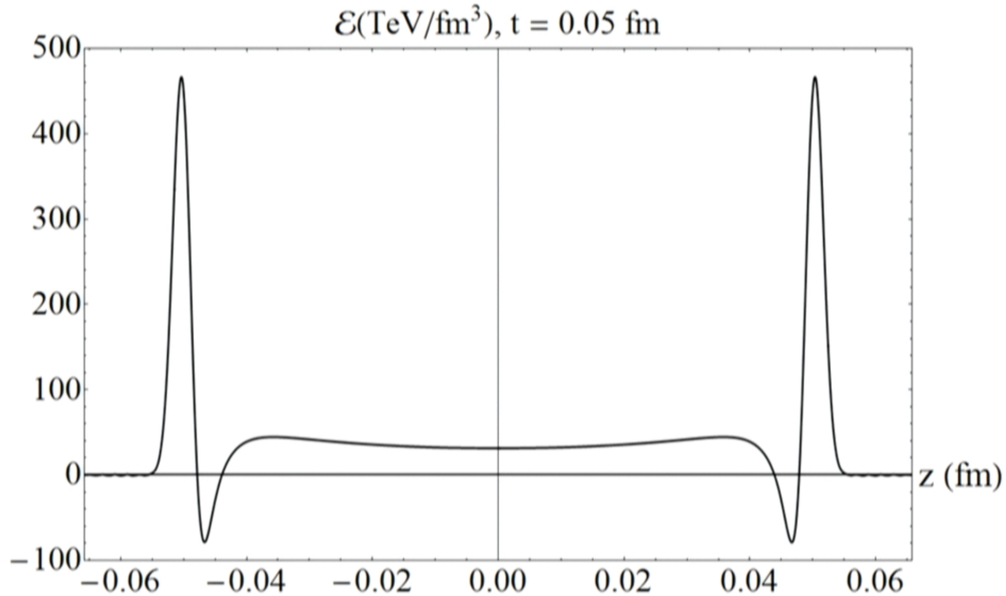
- Comparable c.o.m. late time results for narrow shocks:



- Plotted at ~ $2t_{hyd}$

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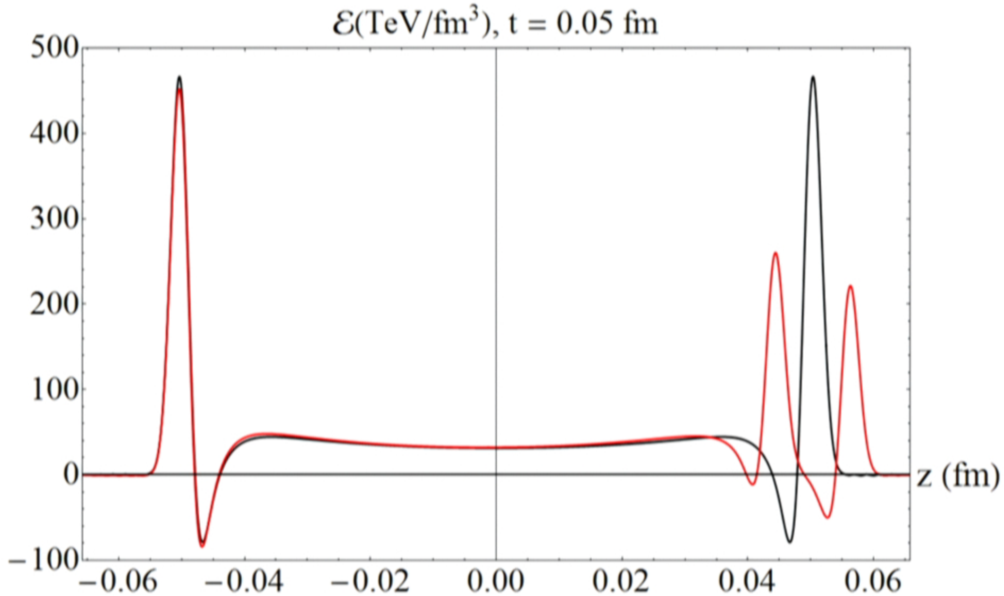


- Plotted at ~ $2t_{hyd}$

A fully dynamical model of a HIC

Work with Paul Romatschke and Scott Pratt

i) Small time expansion of colliding shocks (central)

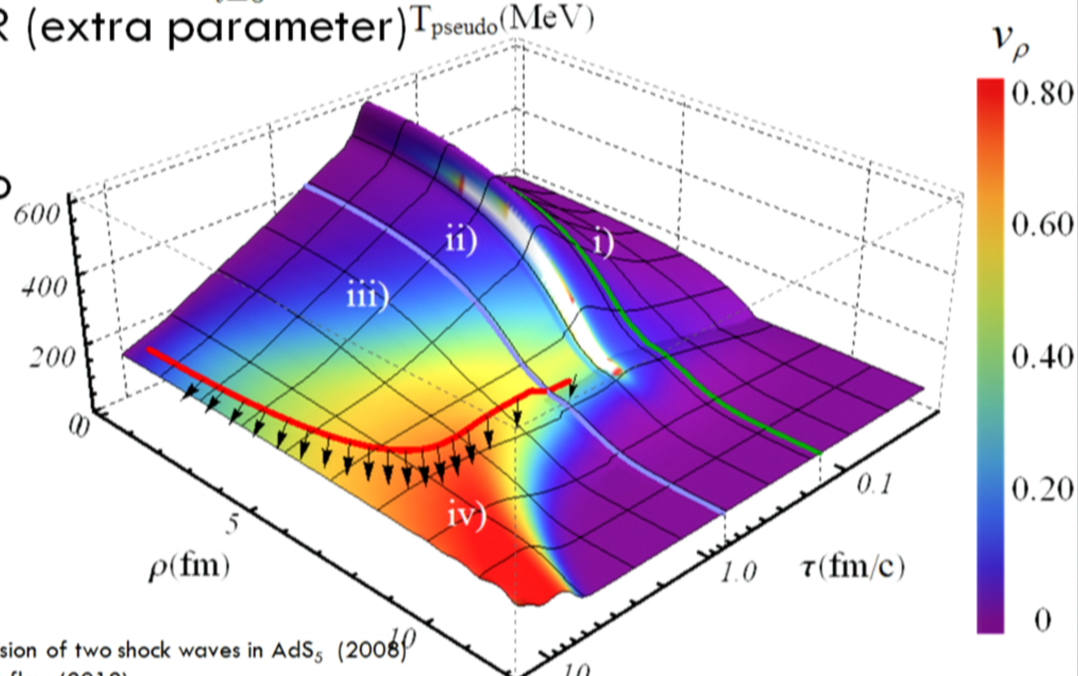
$$B(r,\tau,\rho) \to B_0(r,\tau,\rho) + \sum_{i=0}^{6} \frac{b_i(\tau,\rho) r^{-i}}{1+\sigma^7 r^{-7}},$$

ii) Numerical GR (extra parameter)

iii) Viscous hydro

iv) Hadronic

cascade



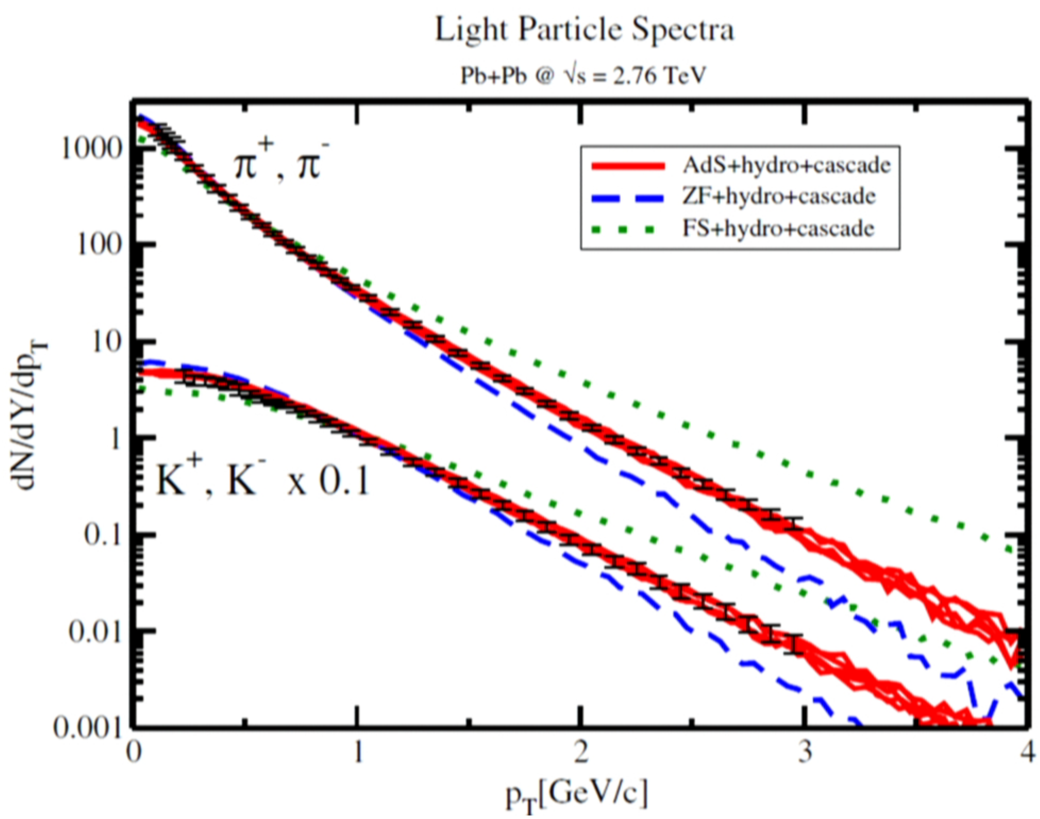
Boost-invariant

P. Romatschke and D. Grumiller, On the collision of two shock waves in AdS_5 (2008)
WS, Holographic thermalization with radial flow (2012)

Boost-invariant radial flow

Wilke van der Schee, Utrecht

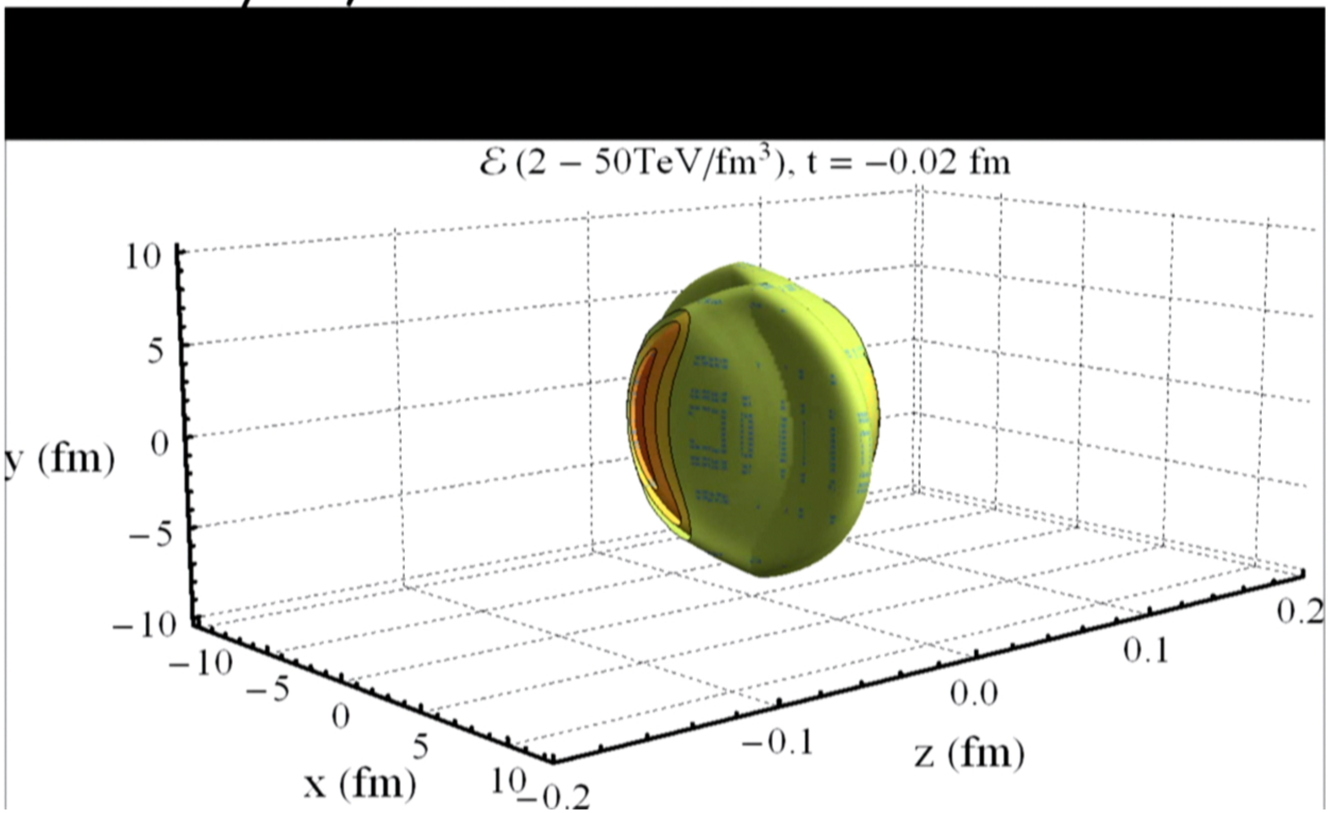
- Spectra ☺



Prospects: colliding nuclei

Wilke van der Schee, Utrecht

- Need hydro, freeze-out etc..



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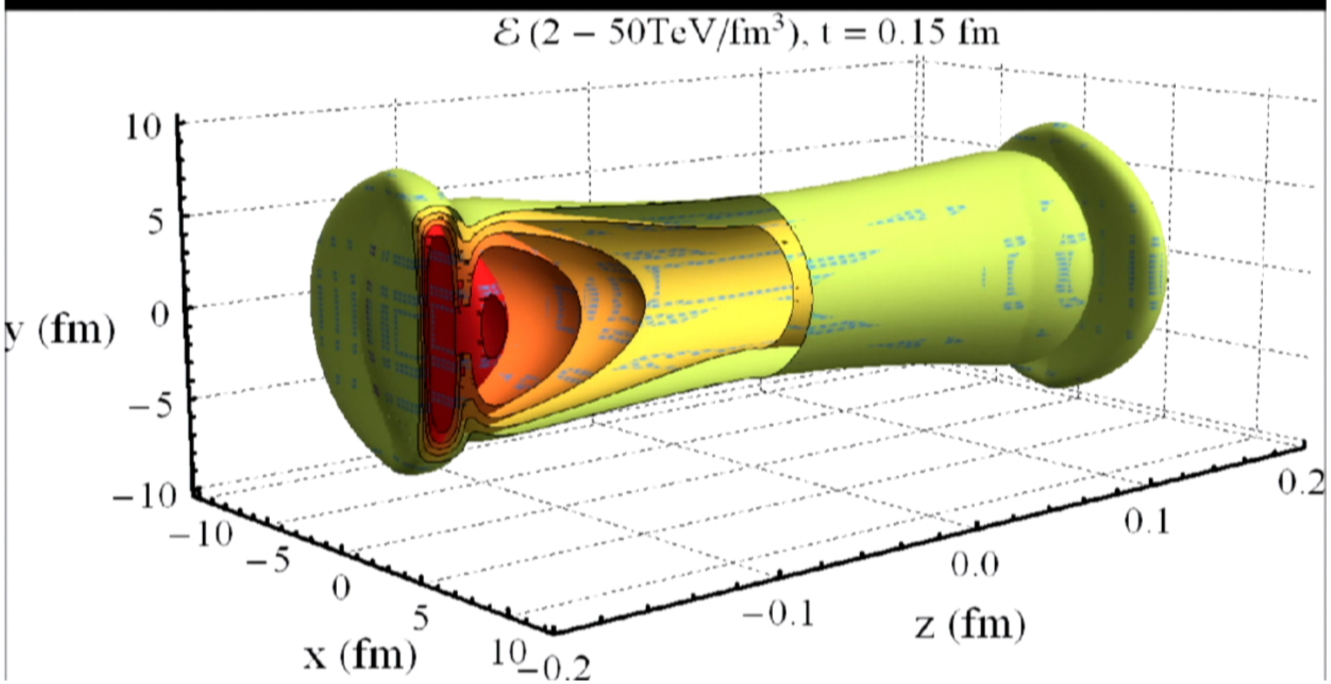

Discussion

Speculative

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- Disclaimer
  - Modeling at infinite N and ***infinite coupling***, at all scales
  - Colliding 'blobs of plasma' = nuclei?
- Shock waves: ***Strong coupling ≠ full stopping***
  - Working hypothesis: shocks provide good model for HIC
  - No boost-invariance @ asymptotically high energies
- Lessons towards experiments
  - ***Pre-flow*** can be produced dynamically
  - Perhaps much higher temperatures (3.7 TeV/fm^3 @ t=0.25 fm?)
  - Perhaps much faster thermalisation (1/T~0.05 fm)
  - Energy density grows initially?
- p-Pb should be symmetric in c.o.m. frame, ***longitudinal coherence***