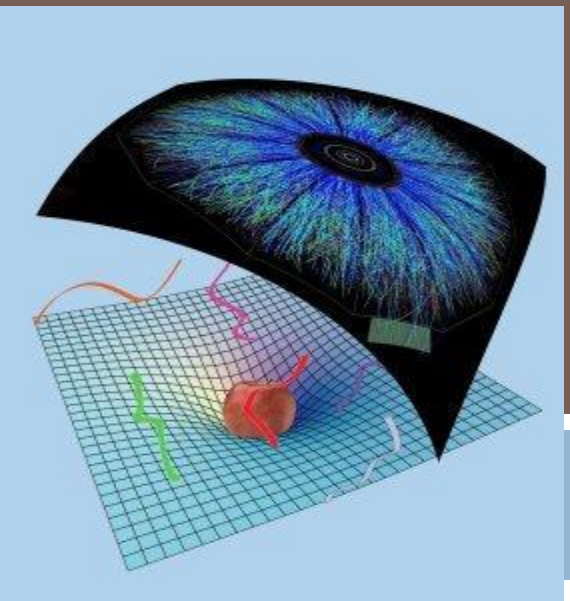
FROM FULL STOPPING TO TRANSPARENCY IN HOLOGRAPHY

Towards more realistic models of the QGP thermalisation

Work with Michał Heller, David Mateos, Jorge Casalderrey, Paul Romatschke and Scott Pratt
References: 1305.4919, 1307.2539



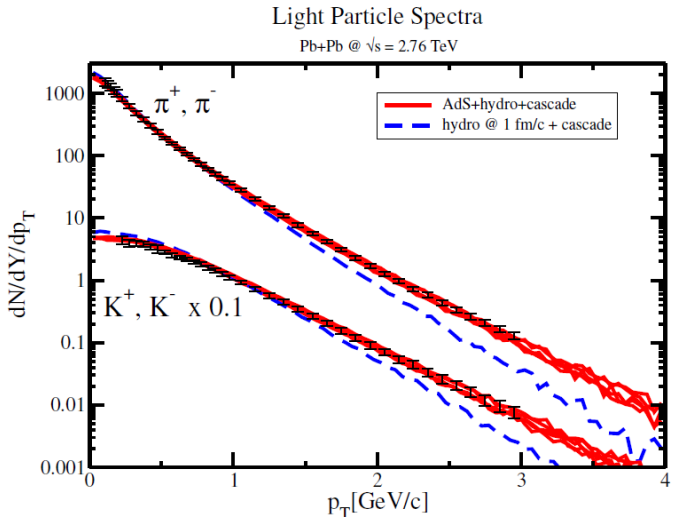
Wilke van der Schee

Supervisors: Gleb Arutyunov,
Thomas Peitzmann and Raimond Snellings

Conference on initial stages of heavy-ion collisions, Ila de Toxa, Spain
September, 2013

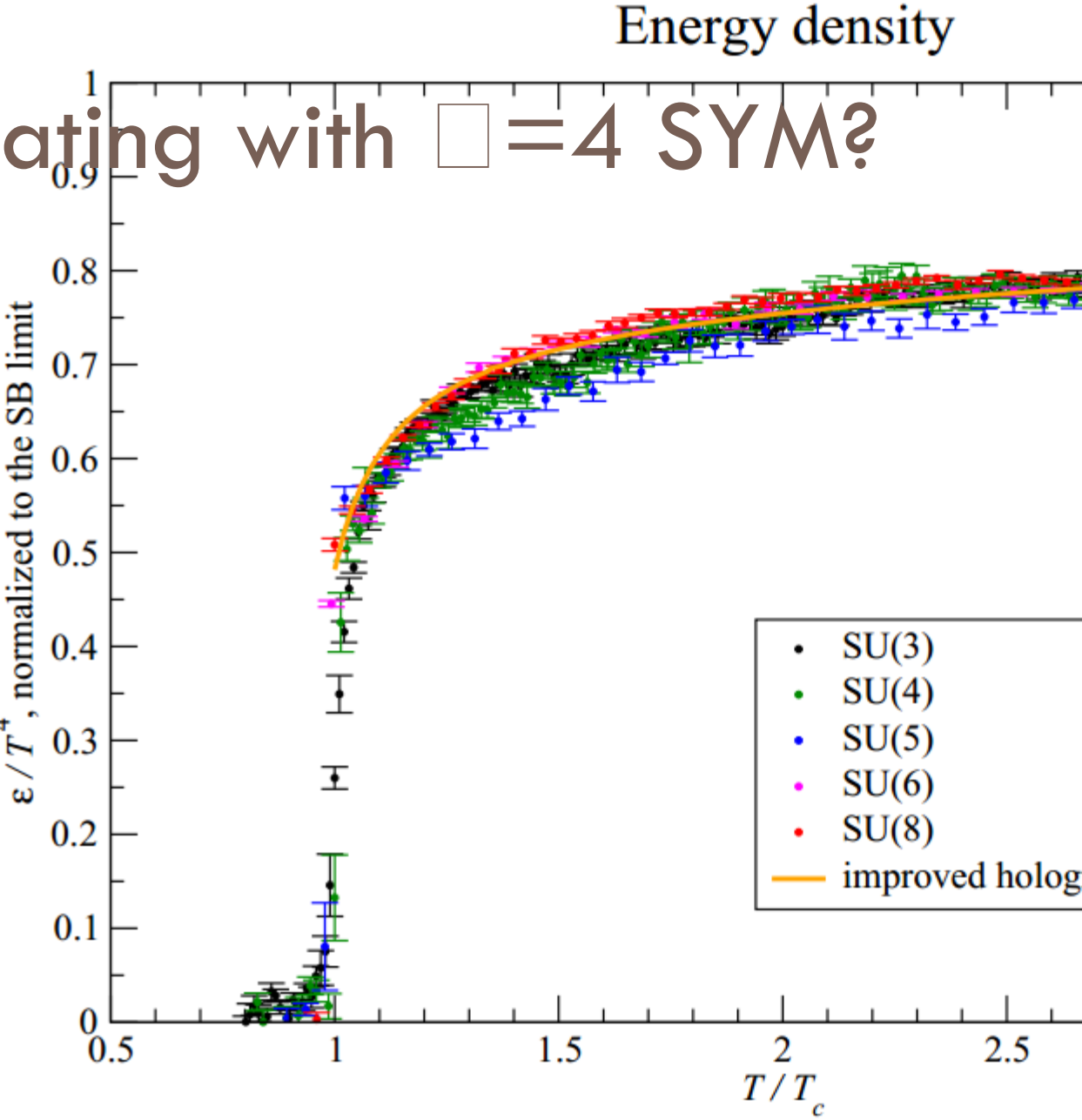
Outline

- Motivation: AdS/CFT
- Gravitational shock waves in AdS
- Towards experiments: boost-invariant radial flow
  - Combination of AdS/CFT+viscous hydro+cascade



Are we cheating with □=4 SYM?

- SU(N): 3 ≈ □?
  - Good for therr
- SUSY?
  - Supressed with
- Quarks?
  - Replaced by (c
- Infinite coupling
  - But coupling ru
- So maybe not too bad, and with room for improvement ☺

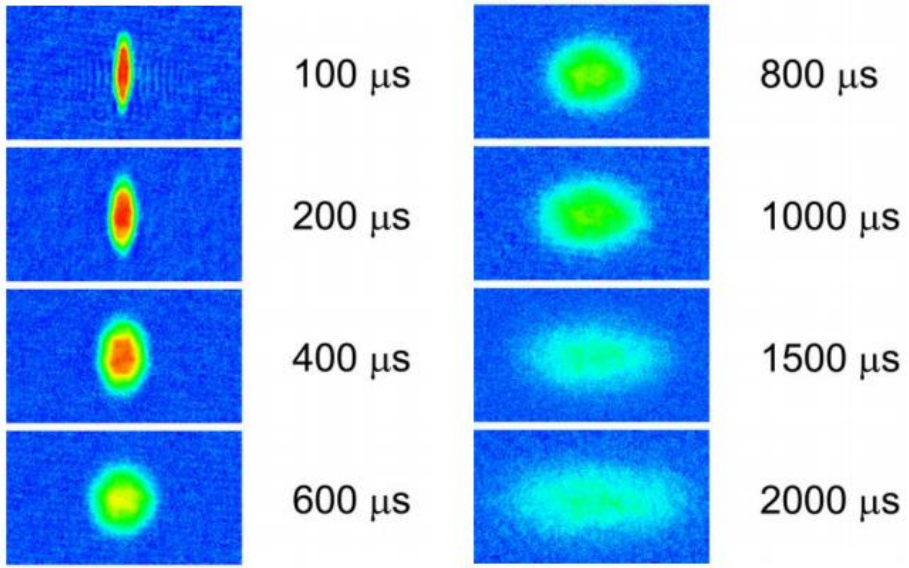


M. Panero, Thermodynamics of the QCD plasma and the large-N limit (2009)

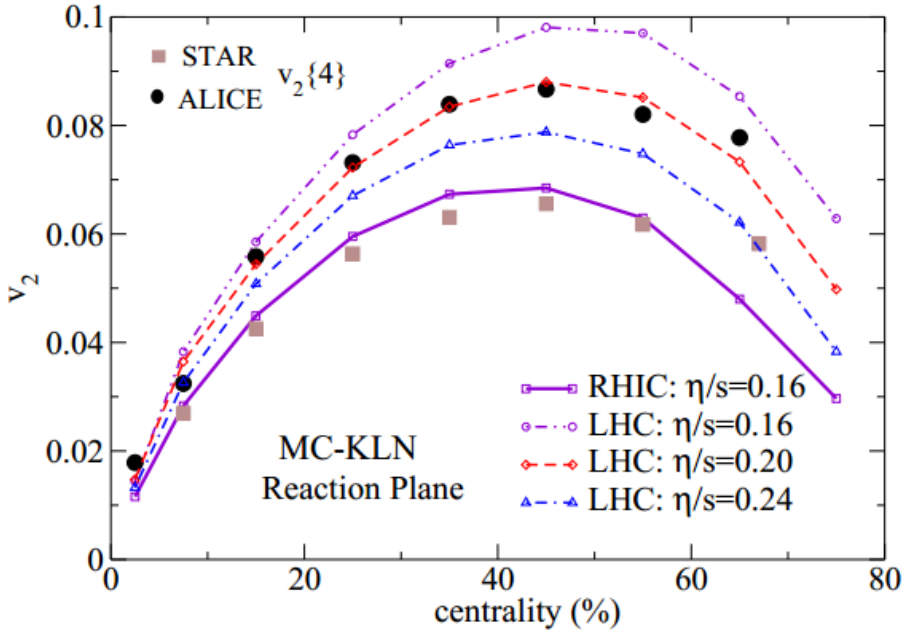
The most perfect liquid?

- Famous viscosity: $\frac{\eta}{s} = \frac{1}{4\pi} \approx 0.08$

Fermions at unitarity



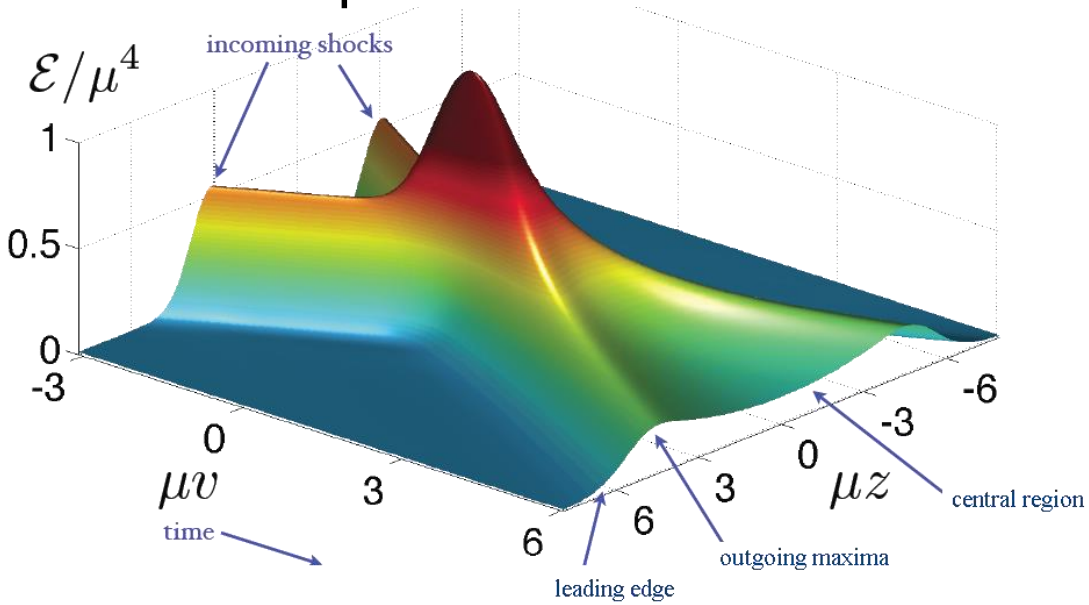
Quark-gluon plasma



K. O'Hara, S. Hemmer, M. Gehm, S. Granade and J. Thomas, Observation of a Strongly-Interacting Degenerate Fermi Gas of Atoms, 2002
U. Heinz, C. Shen and H. Song, The Viscosity of Quark-Gluon Plasma at RHIC and the LHC, 2011

Shock waves – initial conditions

- Famous example:



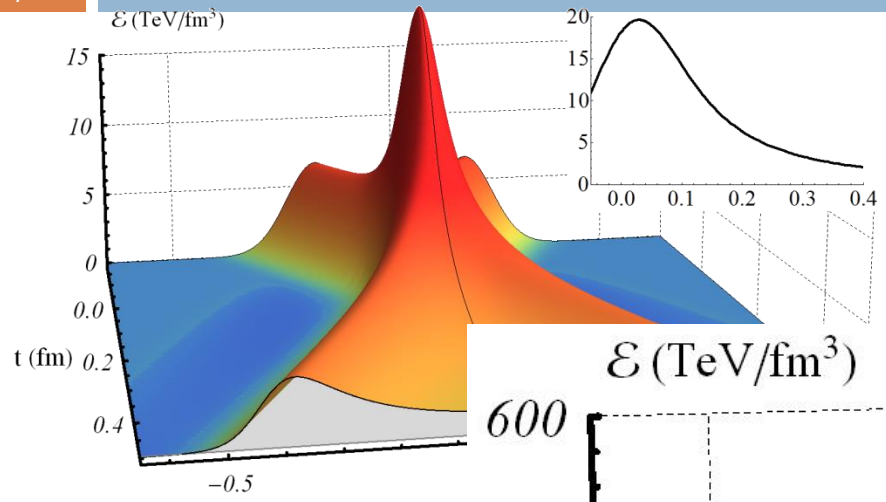
Extra AdS direction

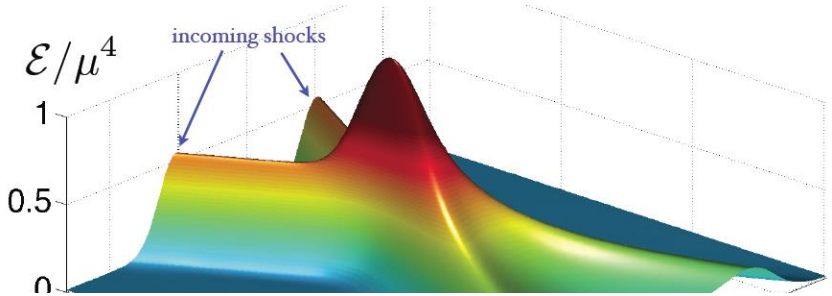
- Homogeneous in transverse plane ('infinite nucleus')
- Energy density moving at speed of light: initial conditions fixed
  - Two scales: width + total energy
- Only gravity: dominant force at high energy

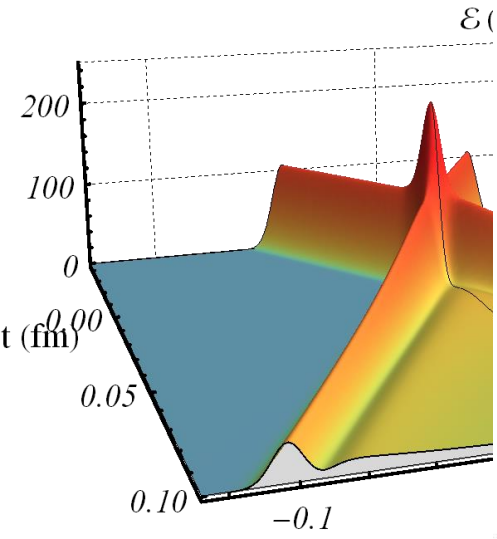
P.M. Chesler and L.G. Yaffe, Holography and colliding gravitational shock waves in asymptotically AdS_5 spacetime (2010)

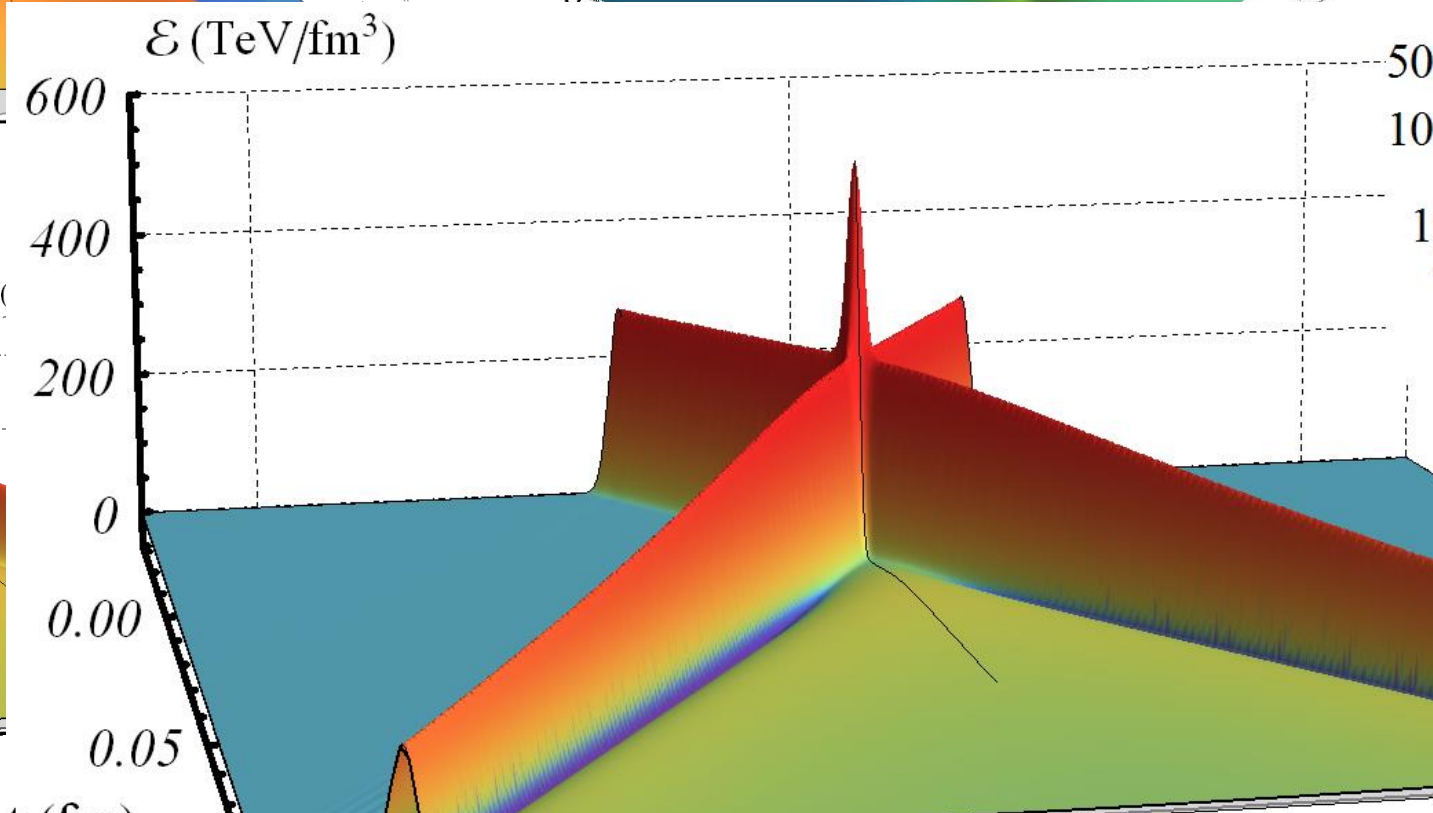
Shock waves – varying the width

Wilke van der Schee, Utrecht



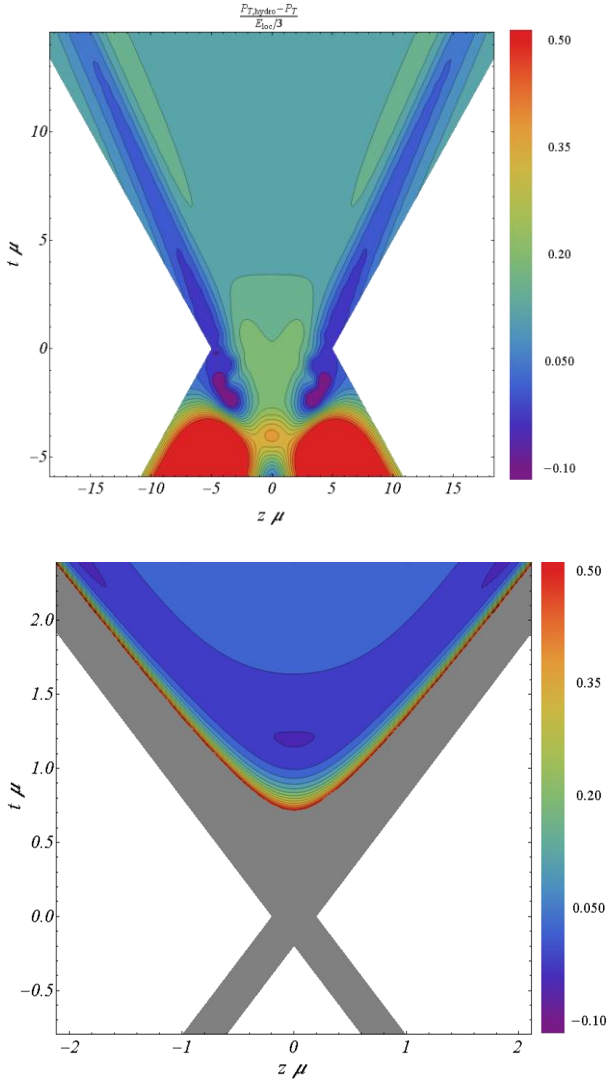






A dynamical cross-over

- Low energy:
  - Stopping, piling up of energy
  - Expansion by hydro
  - Compressed Landau model
- RHIC energy
  - Landau model
- High energy:
  - no stopping
  - plasma forms slowly
  - negative energy

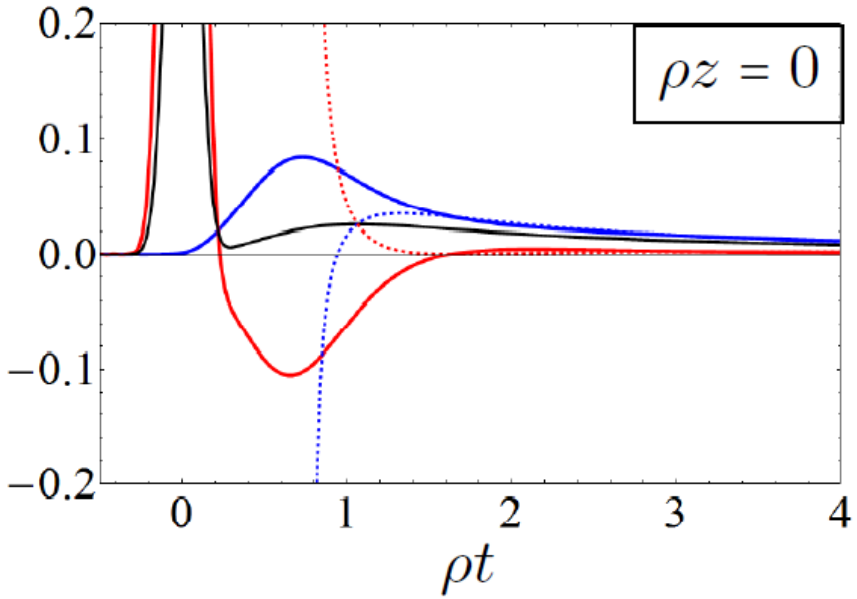


Pressure anisotropy

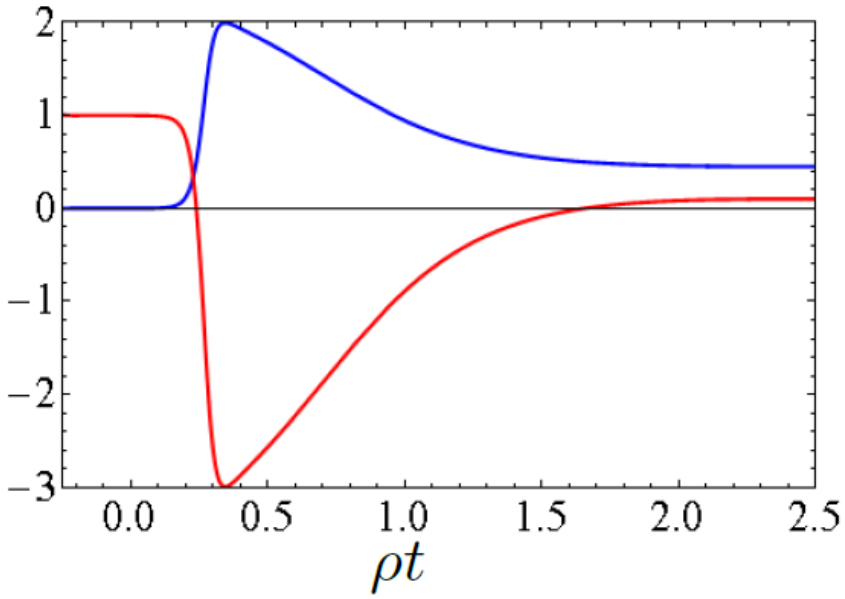
- Pressure & energy starts at zero, grows

- Can give large negative longitudinal pressure:

$\mathcal{E}/3\rho^4$ (black), $\mathcal{P}_L/\rho^4$ (red) and $\mathcal{P}_T/\rho^4$ (blue)



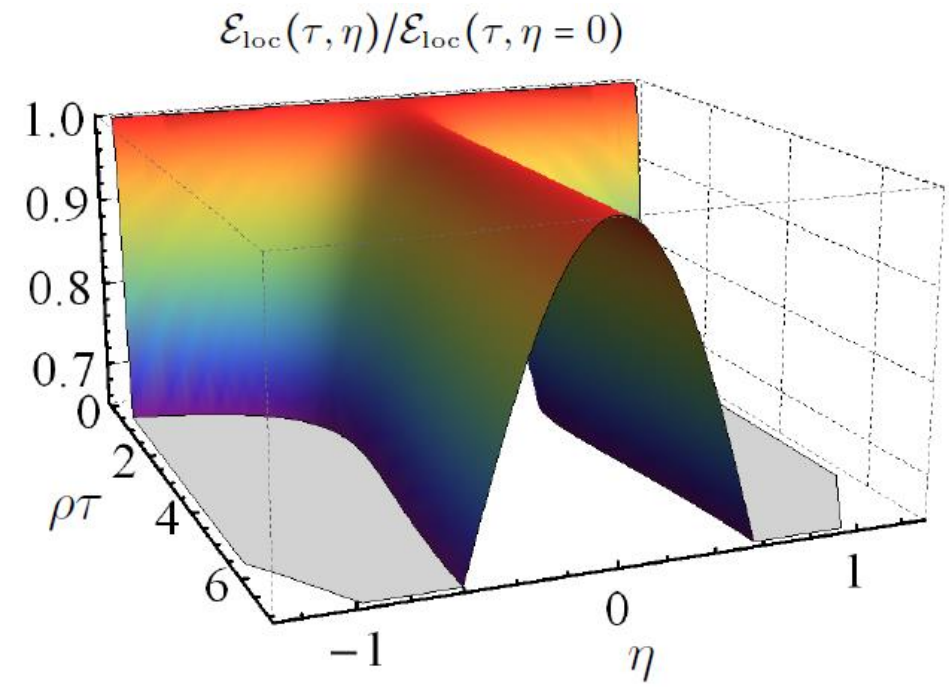
$\mathcal{P}_L/\mathcal{E}$ (red) and $\mathcal{P}_T/\mathcal{E}$ (blue)



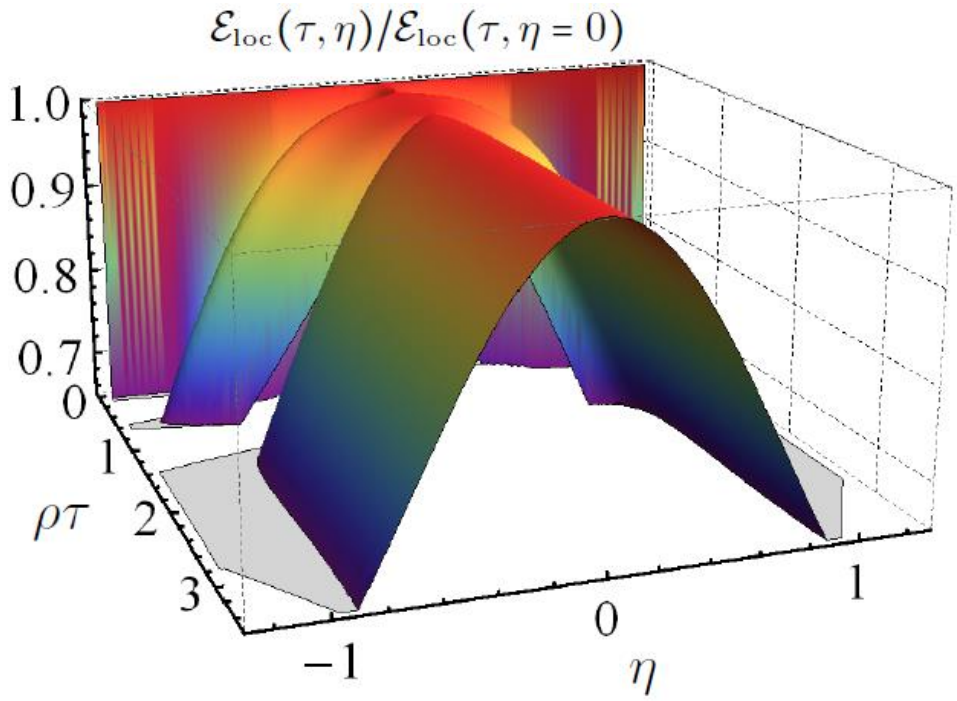
Shock waves – boost-invariance

- No boost-invariance
  - Profile approx gaussian with slightly increasing width

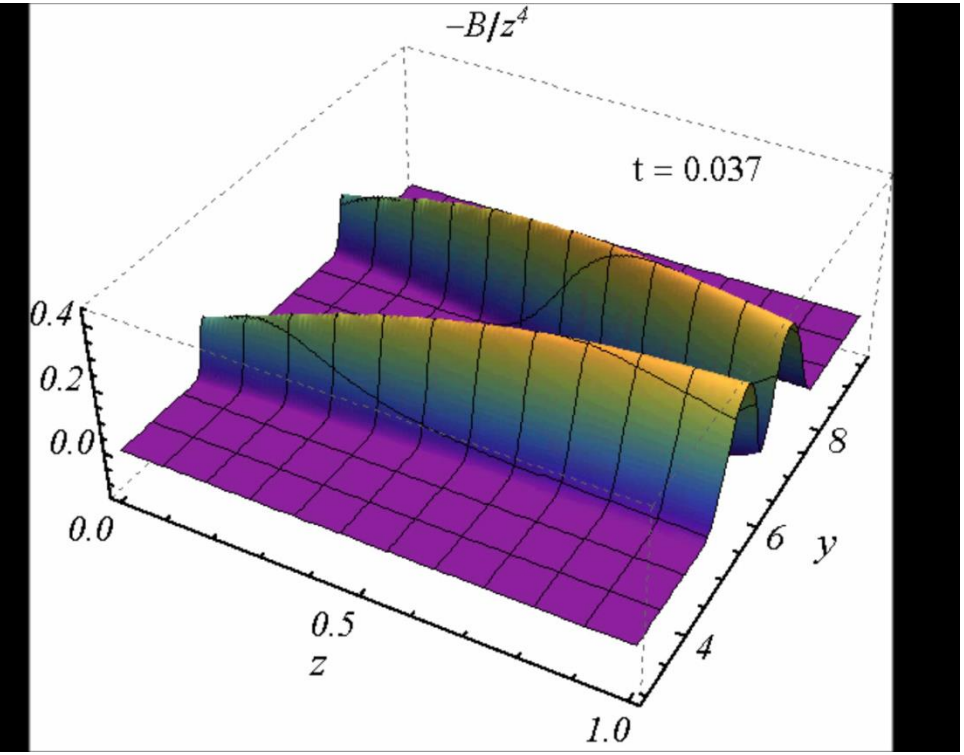
Low energy:

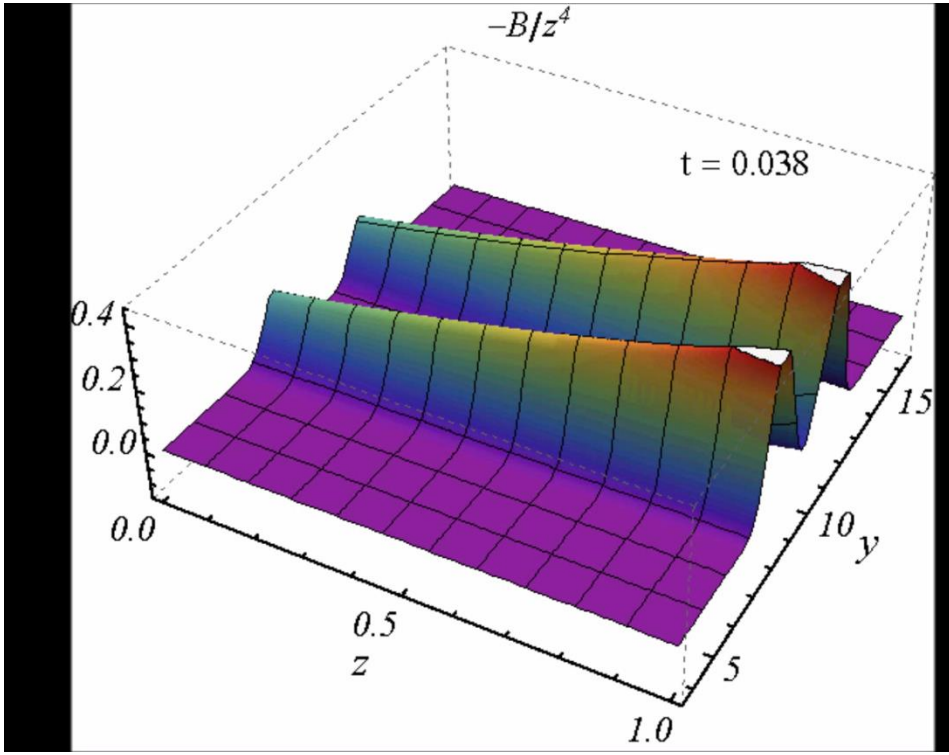


High energy:



Dynamics in AdS – in movies





- Intuition: compare scales 1/Temperature and width
  - Perhaps pancake at RHIC is not so thin?

A fully dynamical model of a HIC

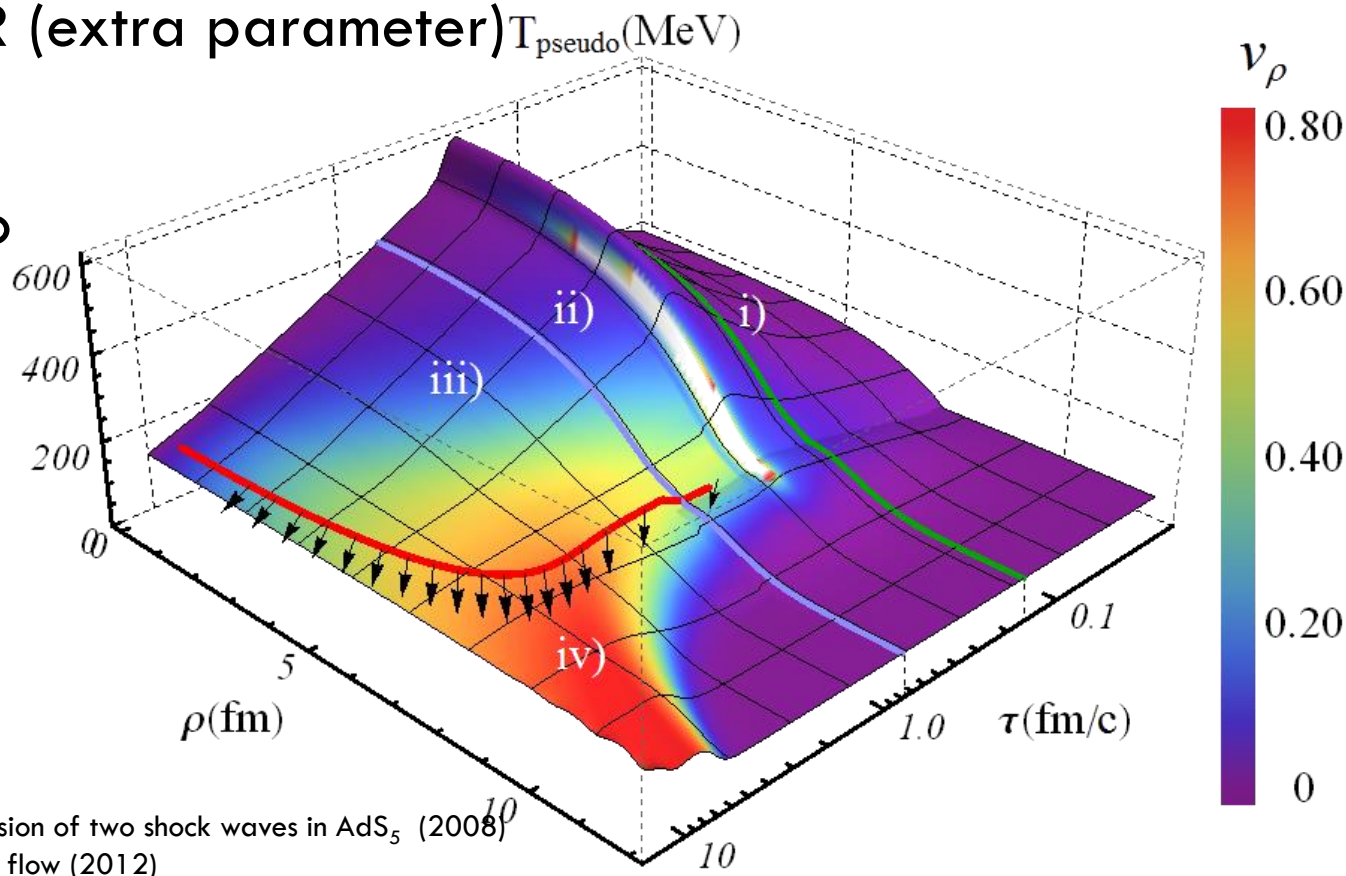
Work with Paul Romatschke and Scott Pratt

i) Small time expansion of colliding shocks (central)

ii) Numerical GR (extra parameter)

iii) Viscous hydro

iv) Hadronic cascade

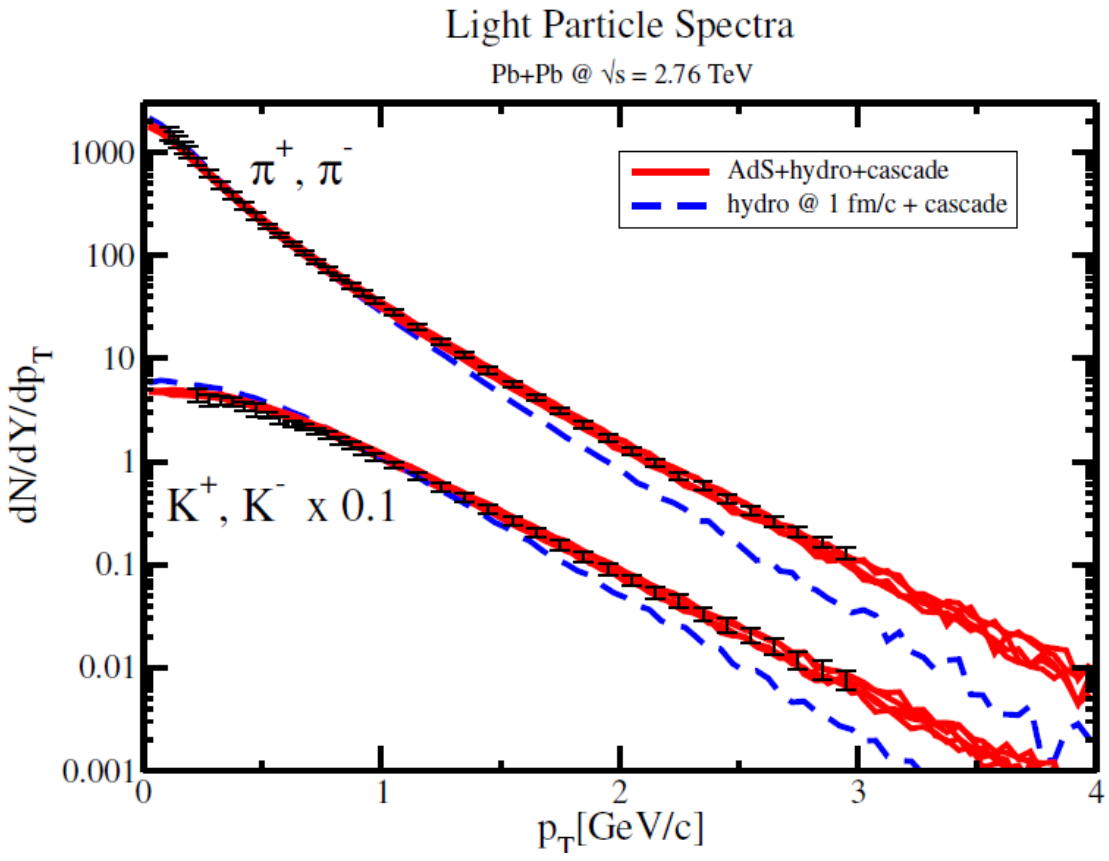


Boost-invariant

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

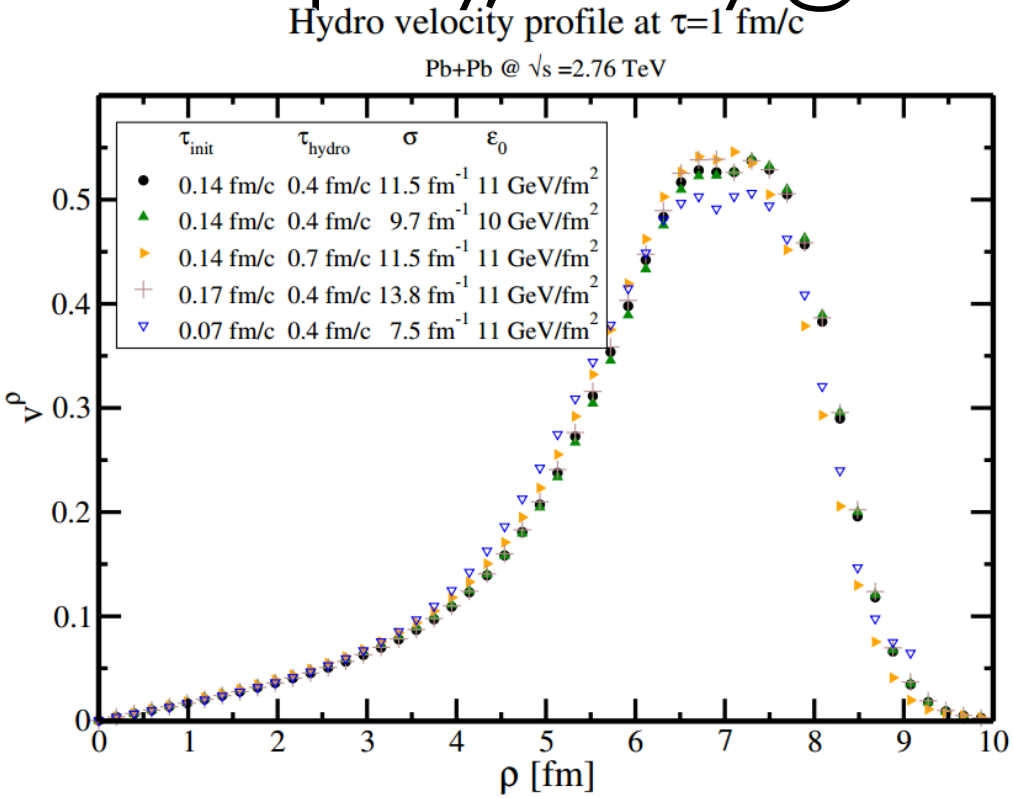
Radial flow – initial conditions

- Spectra ☺



Results – approach to hydro

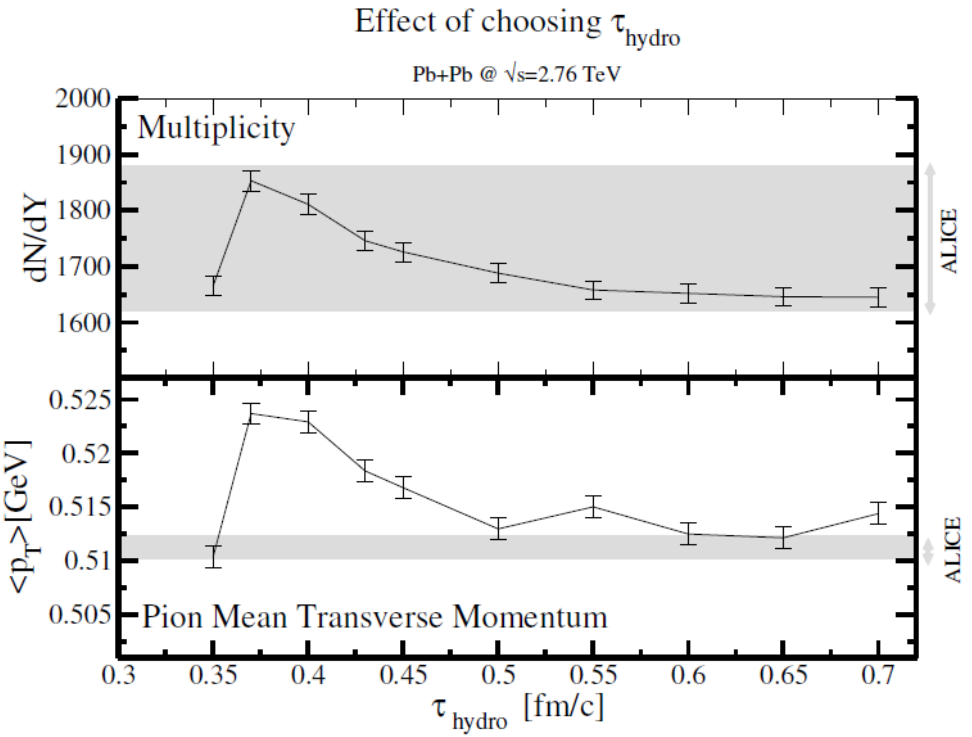
- Fixing total multiplicity, velocity @ 1 fm/c:



- Velocity profile approx universal; little depedence on initial AdS time, extra AdS parameter

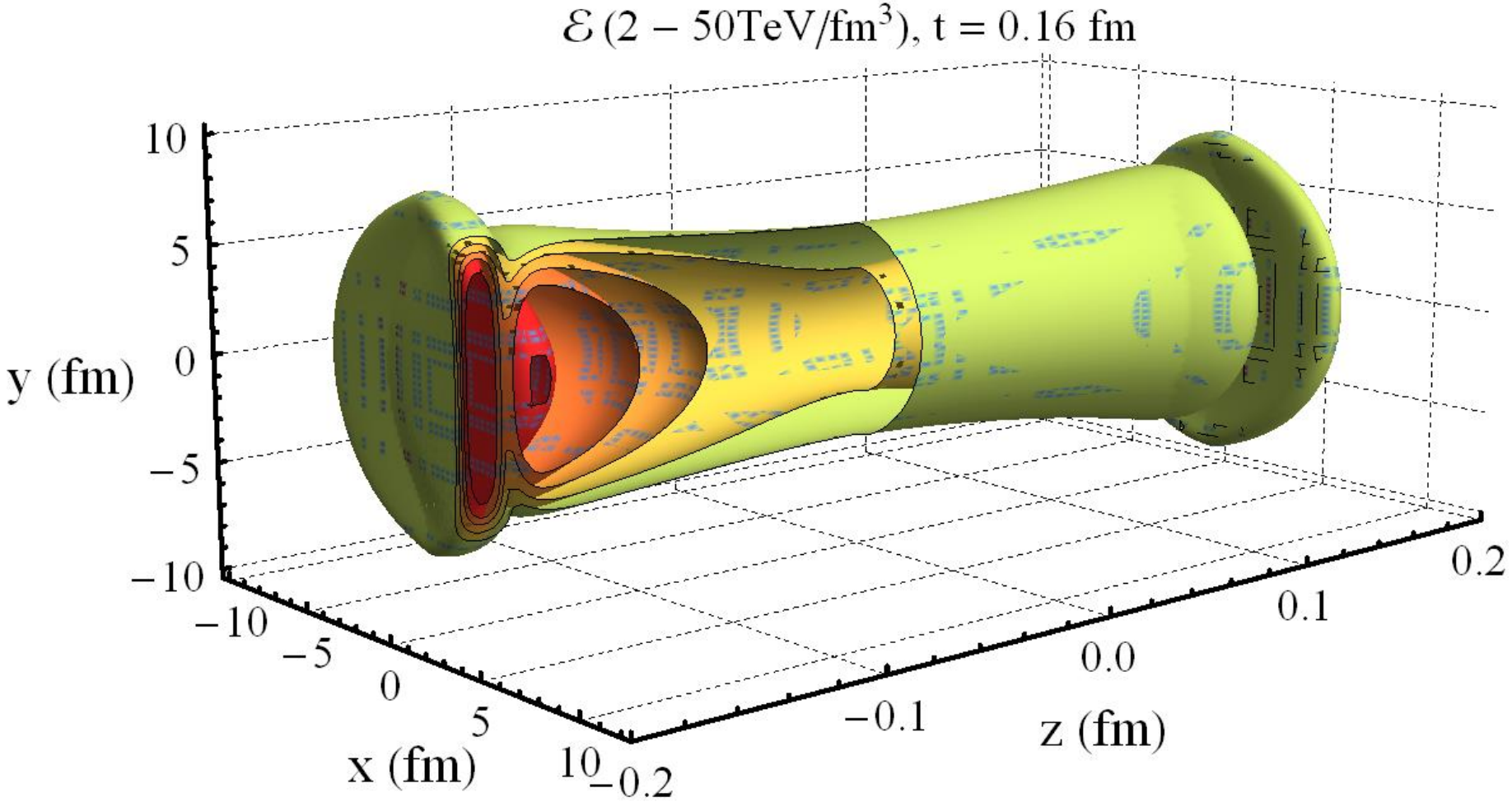
Results – approach to hydro

- Not too early: far-from-equilibrium
  - Rest frame does not even exist!
- Not too late: AdS = conformal ≠ QCD
  - In practice: 15% discontinuity in pressure



Prospects: a combination

- Need hydro, freeze-out etc..

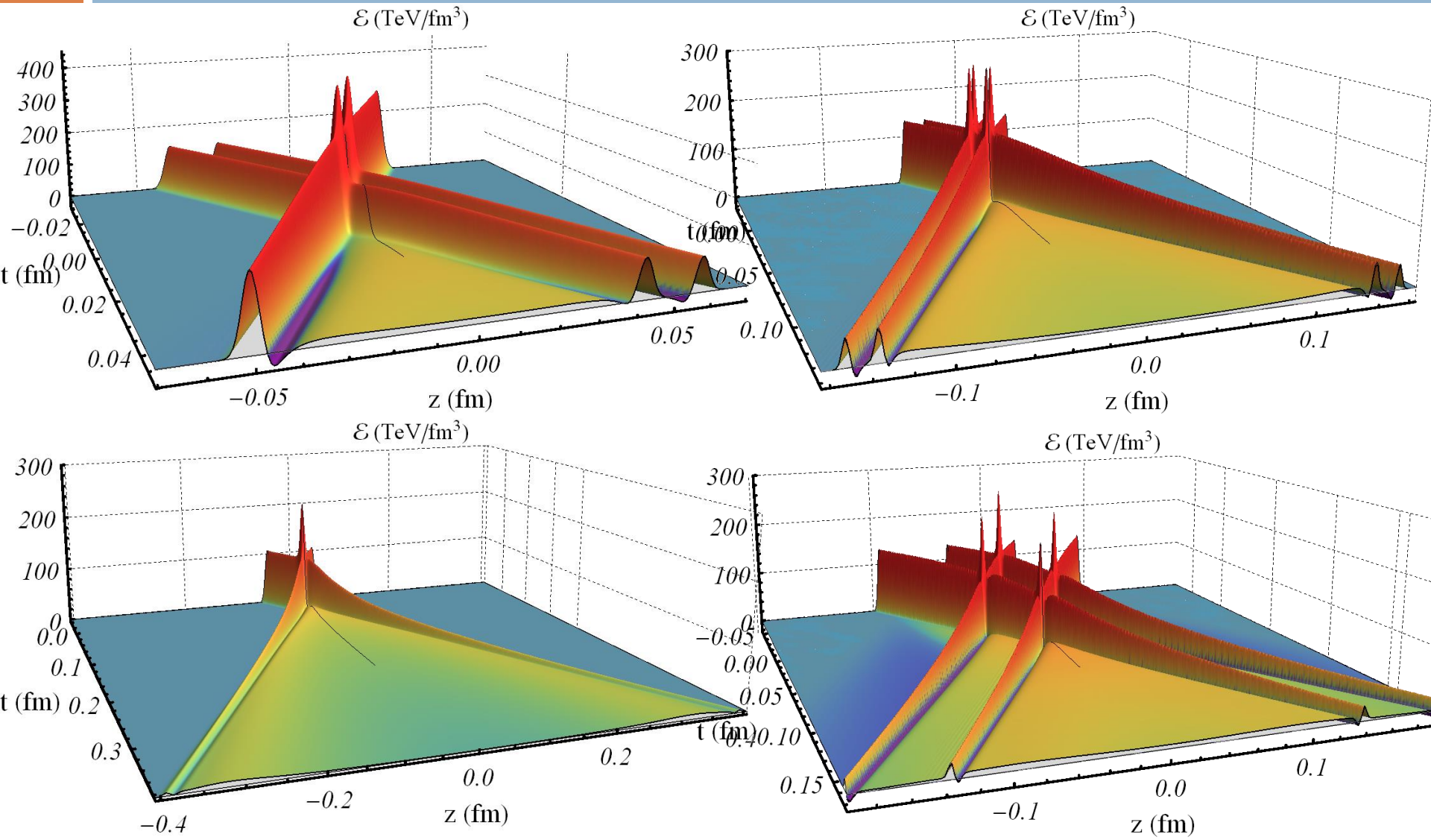


Discussion

Speculative

- 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
- Lessons towards experiments
  - Pre-flow can be produced dynamically
  - Perhaps higher temperatures (1.8 TeV/fm^3 @ t=0.25 fm?)
  - Perhaps faster thermalisation (0.25/T~0.25/GeV~0.05 fm)
  - Energy density grows initially?
- Curious: shocks give Landau model precisely at RHIC!

Prospects: microstructure, p-Pb, longer runs



More anisotropy

- Boost-invariance with 0 initial energy:

$$T_{\mu\nu} = \mathrm{diag}\left\{\epsilon(\tau),\ -\tau^2(\epsilon(\tau)+\tau\epsilon'(\tau)),\ \epsilon(\tau)+\frac{1}{2}\tau\epsilon'(\tau),\ \epsilon(\tau)+\frac{1}{2}\tau\epsilon'(\tau)\right\}.$$

- Anisotropy P_L/P_T in radial flow: