Extending the fluid dynamic description of heavy-ions collisions to times before the collision

A. Kirchner[1], A. Erschfeld[2], F. Capellino[3], S. Floerchinger[2], E. Grossi[4]

1 ITP Heidelberg; 2 TPI Jena; 3 University Heidelberg; 4 Dipartimento di fisica e astronomia, Universita di Firenze and INFN Sezione di Firenze

kirchner@thphys.uni-heidelberg.de

This work is part of and supported by the DFG Collaborative Reasearch Center SFB 1225 (ISOQUANT).

Motivation

Transition from initial state model to fluid dynamic simulation often afflicted by theory/model uncertanties

→ Is there a more general way to describe this transition?

→ Can hydrodynamics be used to describe the full collision?

Concept

- Describe incoming nuclei as liquid drops on the nuclear phase transition
- Fluid dynamic description → energy-momentum tensor $T^{\mu\nu}$
- Full collision system described by $T^{\mu\nu}_{\text{coll}} = T^{\mu\nu}_{\rightarrow} + T^{\mu\nu}_{\leftarrow}$
- Fluid fields obtained via Landau matching $T^{\mu}_{\nu} u^{\nu} = -\epsilon u^{\mu}$

Equations of motion

Energy-momentum & baryon number current conservation

$$\nabla_\mu T^{\mu\nu} = 0 \qquad \nabla_\mu n^\mu = 0$$

Second order Israel-Stewart + diffusion current equations

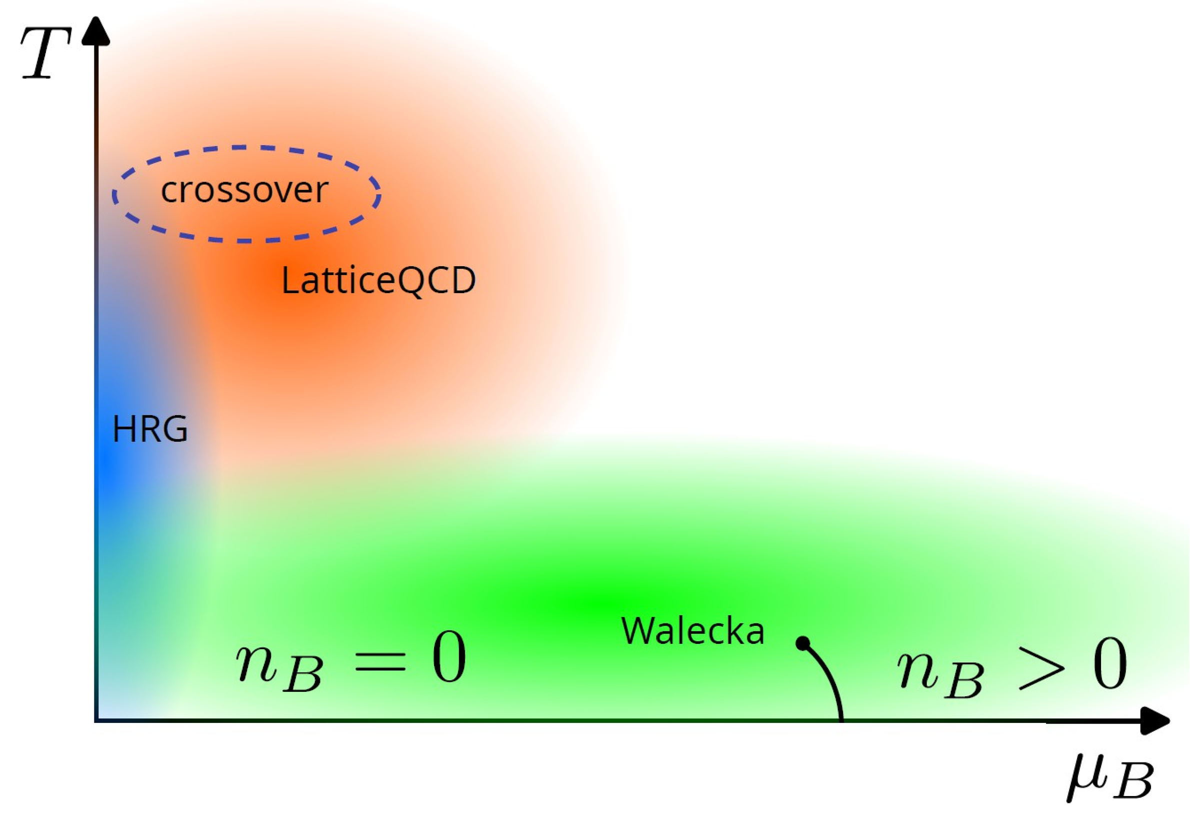
→ Relaxation time ensures validity outside of equilibrium

$$\tau_H \Delta^\alpha_\beta u^\mu \nabla_\mu \nu^\beta + \nu^\alpha + \kappa \left(\frac{nT}{\epsilon + p}\right)^2 \Delta^{\alpha\beta}\partial_\beta \left(\frac{\mu_B}{T}\right) = 0$$

$$P^{\mu\nu\rho}_{\sigma}\left[\tau_S(u^\lambda \nabla_\lambda \pi^\sigma_\rho - 2\pi^{\sigma\lambda}\omega_{\rho\lambda} + 2\eta\nabla - \rho u^\sigma)\right] + \pi^{\mu\nu} = 0$$

$$\tau_{\text{Bulk}} u^\mu \partial_\mu \pi_{\text{Bulk}} + \zeta \nabla_\mu u^\mu = 0$$

Equation of state



Walecka model - effective model of protons and neutrons with omega and scalar meson exhange

$$\mathcal{L} = \bar\psi(i\gamma^\mu\partial_\mu - m_N + g_\sigma\sigma - g\omega\gamma^\mu\omega_\mu)\psi + \frac{1}{2}(\partial_\mu\sigma\partial^\mu\sigma - m_\sigma^2\sigma^2) - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu$$

Pressure from protons+neutrons modified by mean-field terms

Initial conditions

Incomming nuclei sit on vacuum-matter phase transition, described by $T^{\mu\nu}_{\rightarrow/\leftarrow} = \epsilon_{\rightarrow/\leftarrow} u^\mu_{\rightarrow/\leftarrow} u^\nu_{\rightarrow/\leftarrow}$

→ Initial energy density $\epsilon = \mu_{\text{crit}} n$

→ EoM simplify to $u^\mu \partial_\mu n = 0$

→ Free streaming nuclei

Full collision system given by sum of incomming nuclei

$$T^{\mu\nu}_{\text{coll}} = T^{\mu\nu}_{\rightarrow} + T^{\mu\nu}_{\leftarrow} \qquad n^\nu_{\text{coll}} = n^\mu_{\rightarrow} + n^\mu_{\leftarrow}$$

Energy-momentum tensor + baryon number current are decomposed to fluid fields (Landau matching)

$$T^{\mu\nu} = \epsilon u^\mu u^\nu + (p + \pi_{\text{Bulk}})\Delta^{\mu\nu} + \pi^{\mu\nu}$$

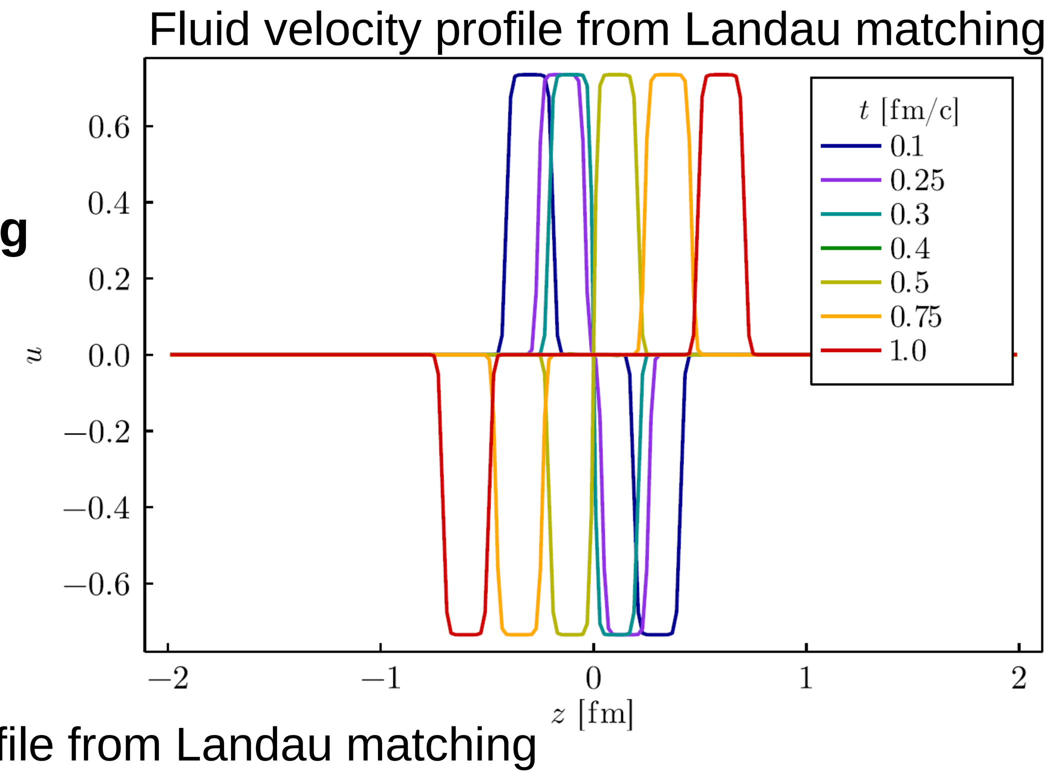
$$n^\mu = n u^\mu + \nu^\mu$$

Non-interacting

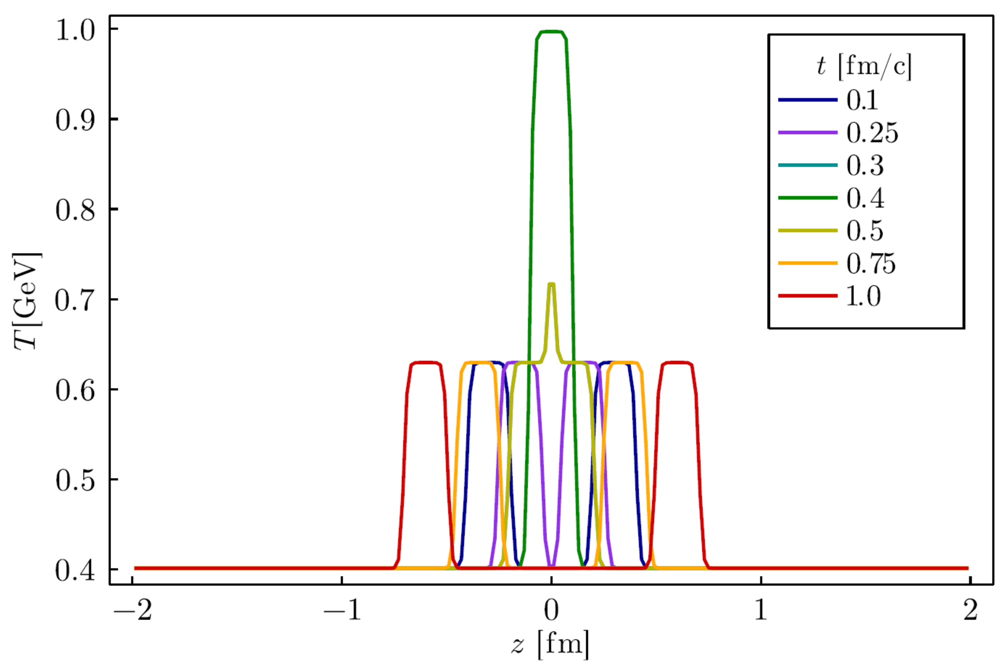
No creation

Bjorken flow

Fluid velocity profile from Landau matching



Temperature profile from Landau matching



System artifically heats up through increased density

Results

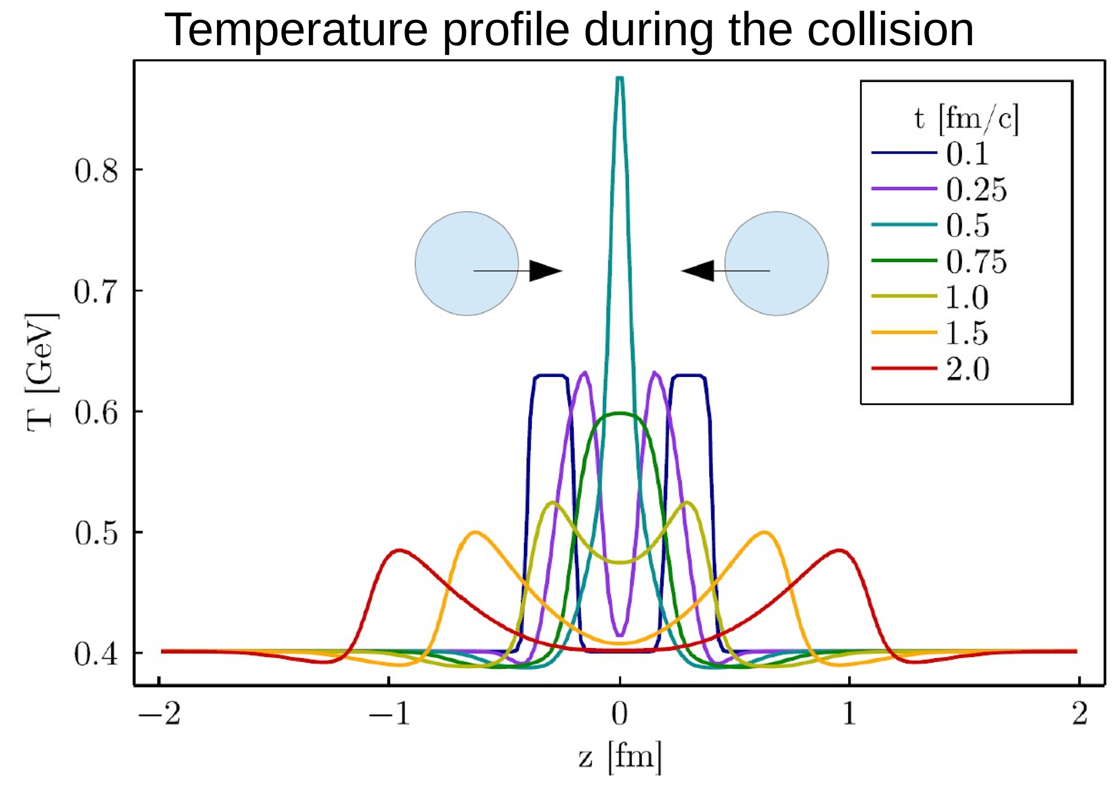
$\sqrt{s} \approx 133$ GeV

Significant heating up

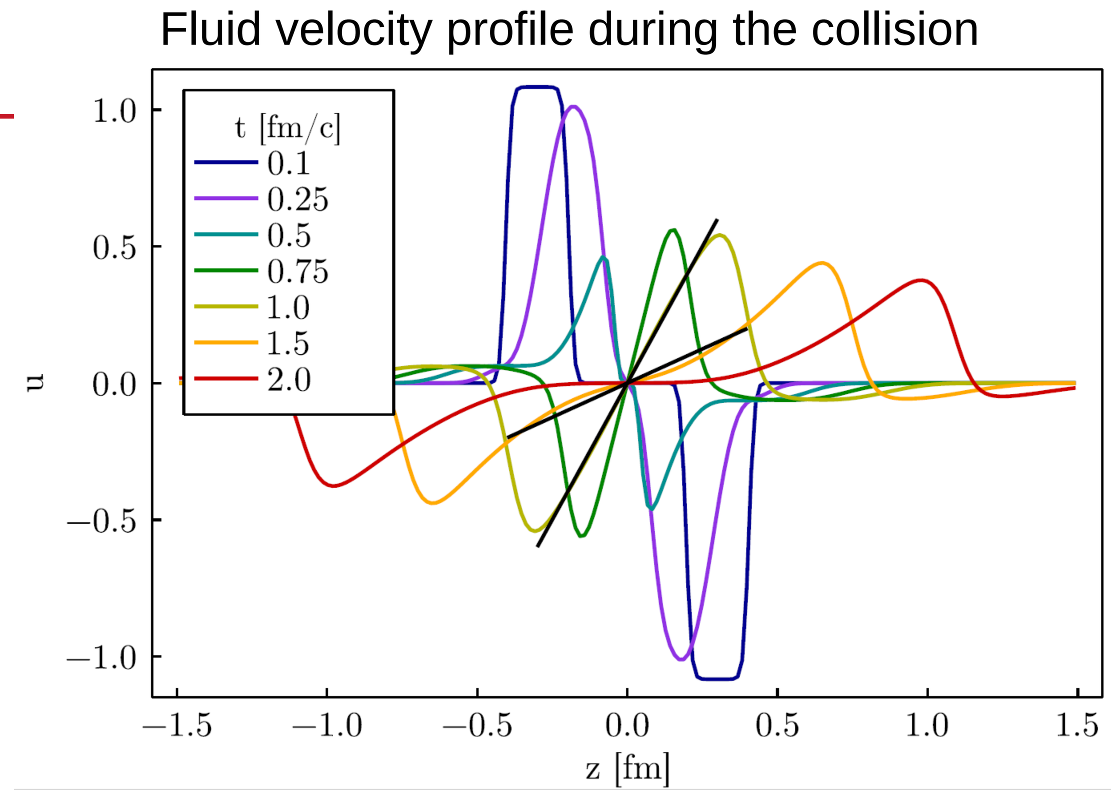
Emergent Bjorken flow

z-invariance at late times

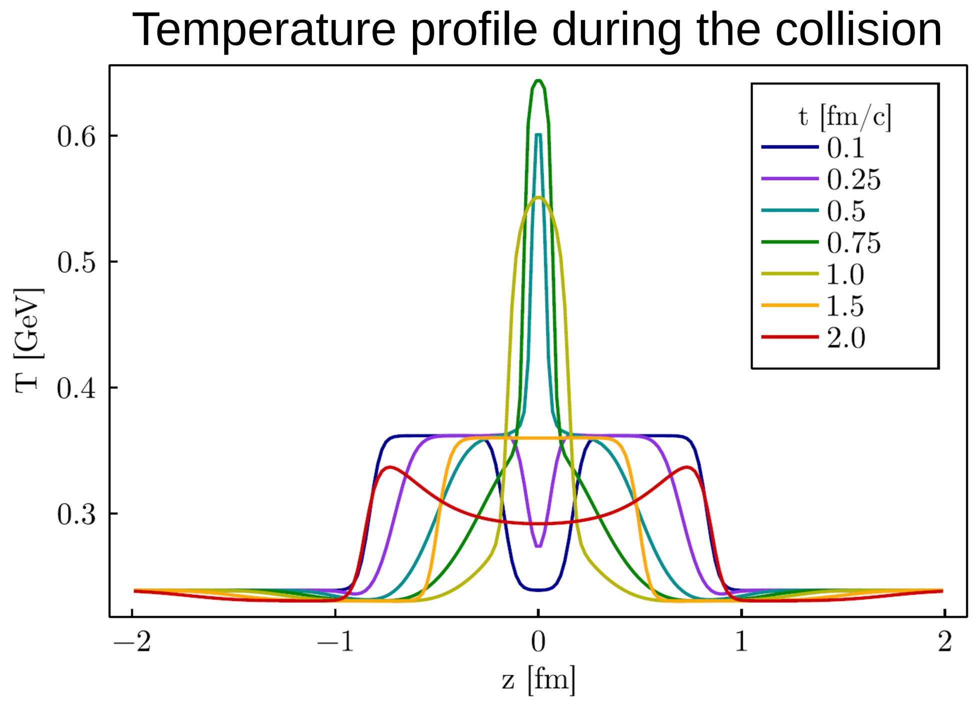
Temperature profile during the collision



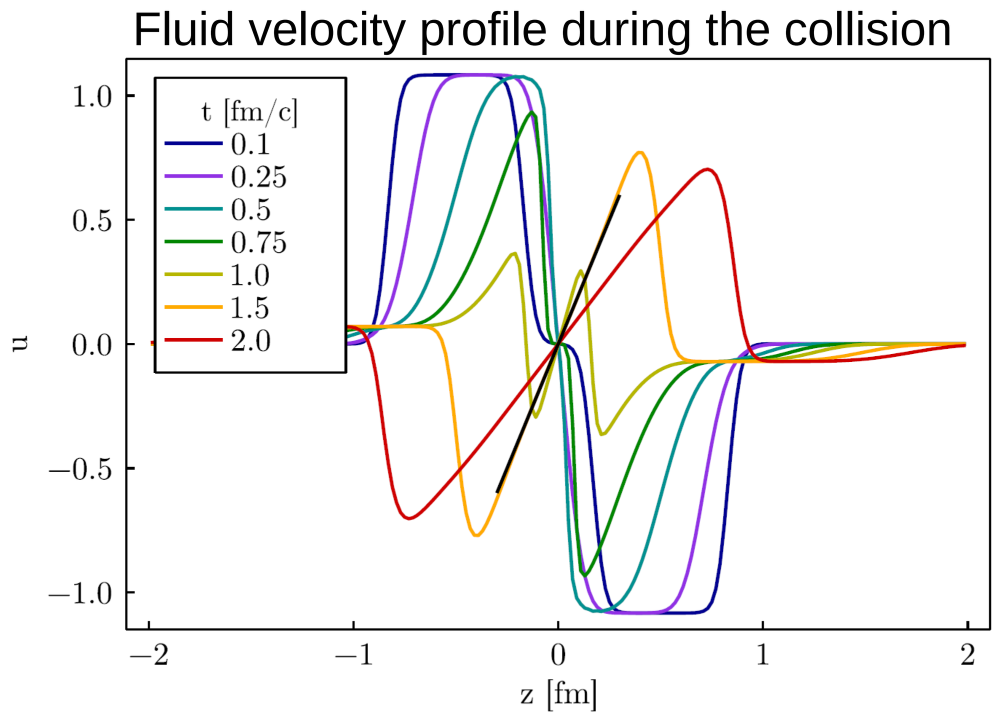
Fluid velocity profile during the collision



Temperature profile during the collision



Fluid velocity profile during the collision



$\sqrt{s} \approx 42$ GeV

Peak temperature and Bjorken flow slope scale with initial collision energy

Outlook

Initialize viscous fields + Improve initial conditions $T^{\mu\nu} = T^{\mu\nu}_{\text{in}} - T^{\mu\nu}_{\text{out}}$ + apply results to traditional hydro