Towards a fluid-dynamic description of an entire heavy-ion collision: from the colliding nuclei to the quark-gluon plasma phase

Duke
QCD theory group

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Phys. Rev. C 112, 024903 (2025)

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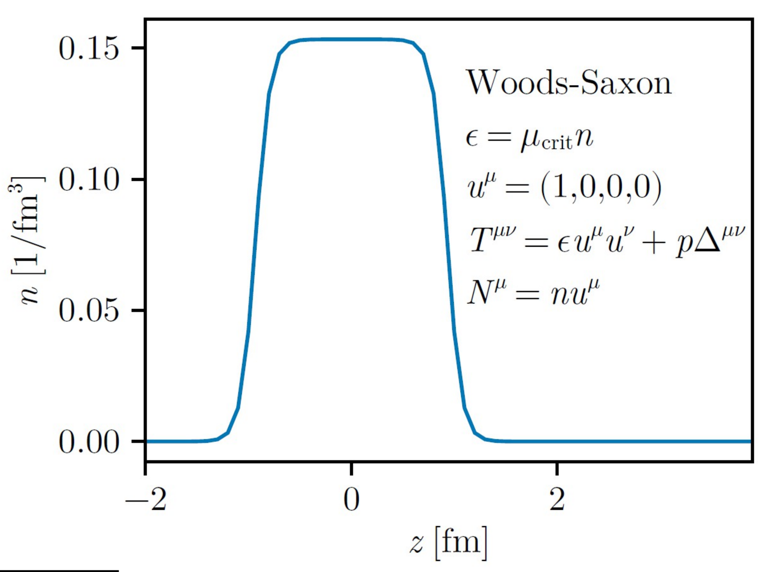
Motivation

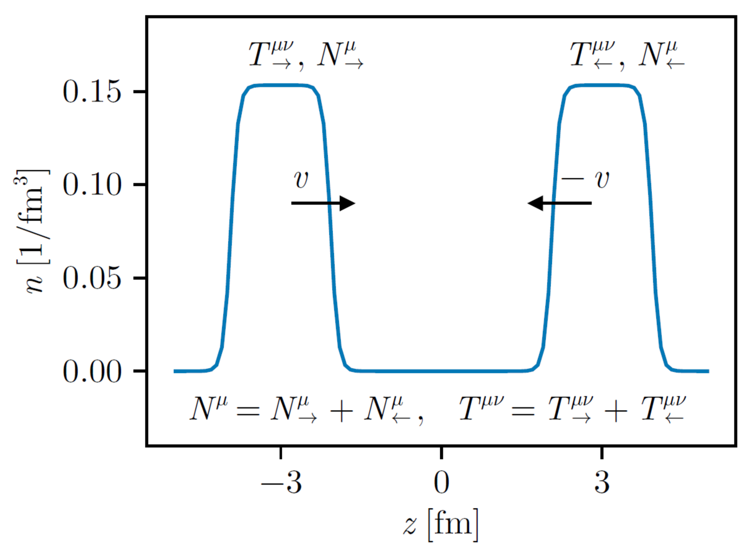
- Examine transition from initial state to fluid dynamics in terms of fluid dynamic degrees of freedom
- Employ description at lower energies to study QCD phase diagram

Setup

Fluid fields via Landau frame matching

$T^{\mu}_{\nu}u^{\nu} = -\epsilon u^{\mu}$





First order phase transition ensures stability

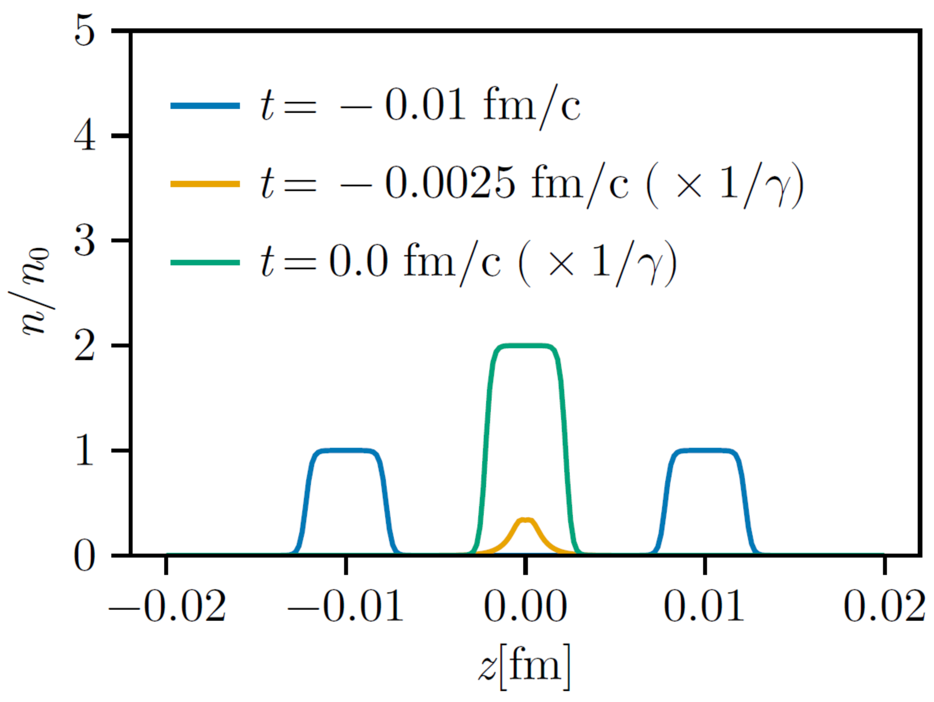
Interactionless limit

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

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

$$n^{\mu} = nu^{\mu} + \nu^{\mu}$$

Large increase of density due to overlap of nuclei & Large viscous fields → Second order fluid dynamics



Take away

- Fully fluid dynamic description
- Only requirements: Density, EoS and viscosity
  → no free parameters
- Trajectory explores phase diagram

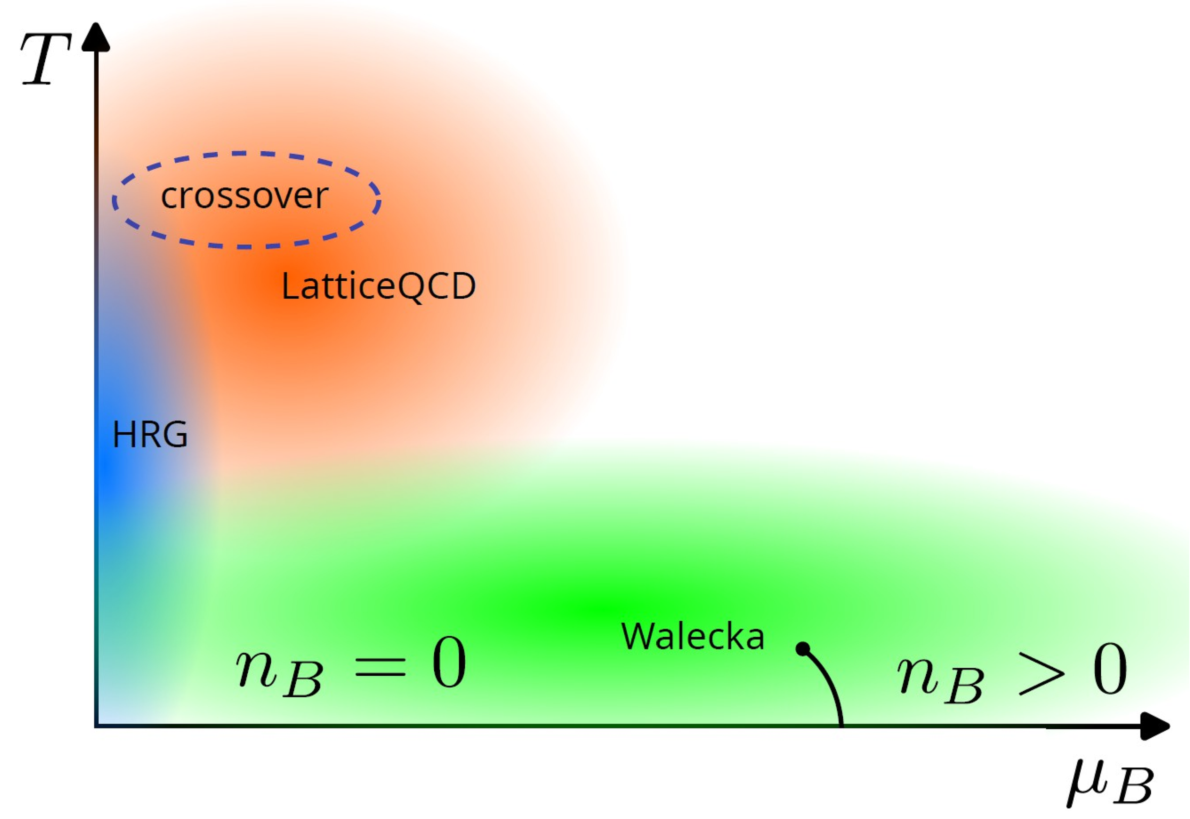
Outlook

- Include phase transitions into EoS & study dynamics at lower beam energies
- Extend model to 1+1D description
- Use QFT calculations for viscosity & relaxation time

Concept

- Fully fluid dynamical description, starting with incoming nuclei
- Equation of motion: Energy-momentum & baryon number current conservation + second order Israel-Stewart $\nabla_{\mu}T^{\mu\nu} = 0$ $\quad \nabla_{\mu}n^{\mu} = 0$
  → Relaxation time ensures validity outside of equilibrium

Equation of state



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

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

Pressure from protons+neutrons modified by mean-field terms

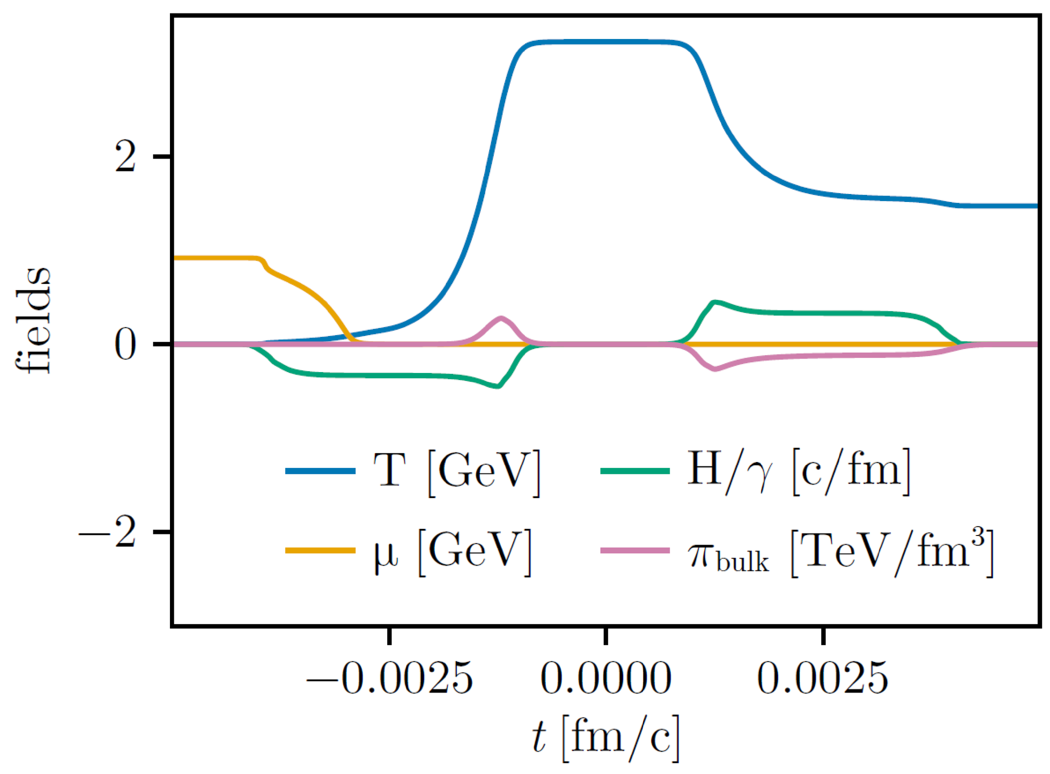
Model system

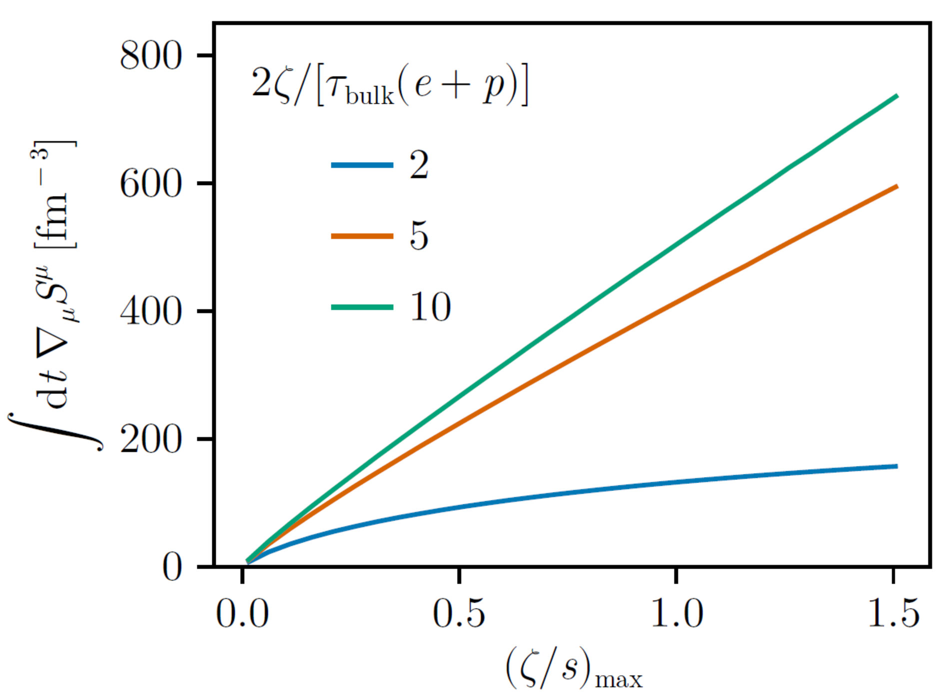
Model compression & expansion of nuclear matter by Hubble universe filled with nuclear matter $\mathrm{d}s^2 = -\mathrm{d}t^2 + a(t)^2(\mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2)$

Fluid fields reduce to $\Phi = (T, \mu, \pi_{\rm bulk})$

Results

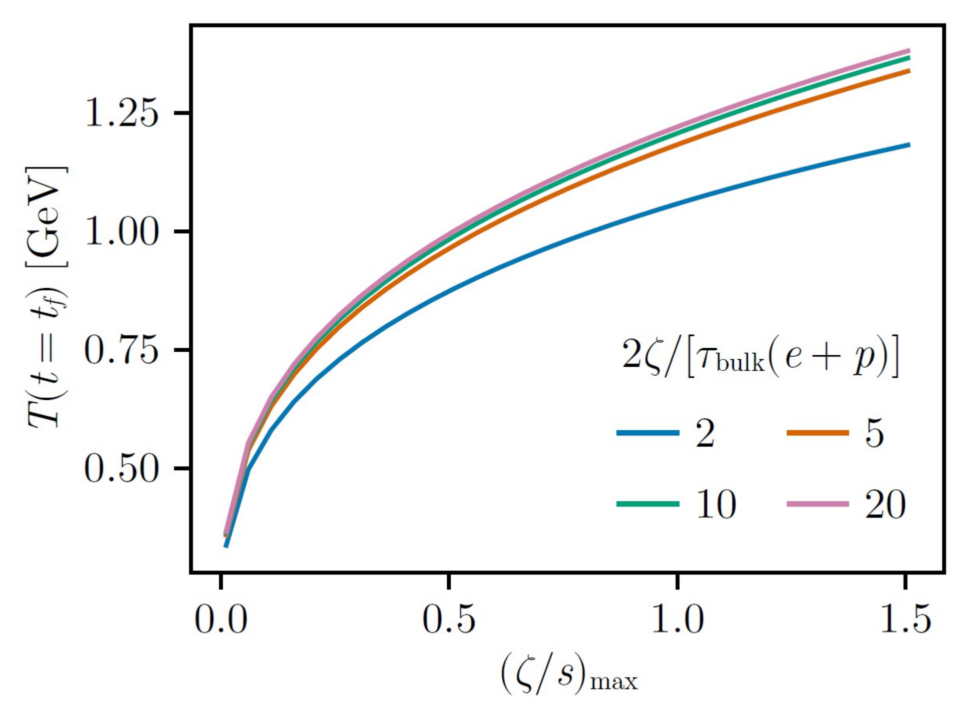
Viscosity creates heat and entropy → final temp. larger than initial temp.





Produced entropy scales with viscosity and inverse relaxation time

Final temperature depends on γ, viscosity and inverse relaxation time



This work is part of and supported by the DFG Collaborative Research Center SFB 1225 (ISOQUANT) and supported by the U.S. Department of Energy, Office of
Science, Office of Nuclear Physics, grant No. DE-FG02-05ER41367.

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