Exploring the high baryon-density regime of the QCD phase diagram within a novel hybrid approach

Motivation and Model Description

- Heavy-ion collisions at intermediate collision energies have become of interest to study the QCD first order phase transition and critical end point
- Experimentally covered by NA61/SHINE, BES II as well as future FAIR and NICA
- Unlike for collisions at low and high energies, there is no theoretical standard approach at intermediate energies yet
- Hybrid approaches are a promising candidate
- In this work: SMASH-vHLLE-Hybrid
- Novel modular hybrid approach for heavy-ion collisions between $\sqrt{s} = 4.3$ GeV and $\sqrt{s} = 5.02$ TeV
- Public: https://github.com/smash-transport/smash-vhlle-hybrid

Results

- Application of SMASH-vHLLE-Hybrid instead of pure transport evolution (SMASH) significantly improves agreement with experimental data
- Transversal and longitudinal baryon dynamics are qualitatively correctly reproduced

Conclusions

- SMASH-vHLLE-Hybrid successfully applied across a wide range of collision energies
- Good agreement with experimental measurements for identified particle spectra and excitation functions
- More dynamical initial conditions [3]
- Impact of EoS on phase transition observables
- Isobar collisions

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Outlook

- More dynamical initial conditions [3]
- Impact of EoS on phase transition observables
- Isobar collisions
The SMASH-vHLLE-Hybrid

**Initial Conditions**
- Propagate particles and perform interactions until hypersurface of constant proper time is crossed
- \( \tau_0 \): geometrical interpretation of the passing time of the two nuclei, but enforcing \( \tau_0 \geq 0.5 \text{ fm} \)
  \[
  \tau_0 = \left( R_p + R_t \right) \sqrt{\left( \frac{s_{\text{NN}}}{2 m_N} \right)^2 - 1}
  \]

**Evolution of the hot and dense fireball**
- Quark gluon phase is evolved according to chiral model EoS
- Particlization on hypersurface of constant energy density: \( e_{\text{crit}} = 0.5 \text{ GeV/fm}^3 \)
- Particlization according to SMASH HRG EoS

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**SMASH**
- Hadronic transport approach
- Initial conditions

**vHLLE**
- 3+1D viscous hydrodynamics (event-by-event)
- CORNELIUS routine to determine freezeout surface

**SMASH-hadron-sampler**
- Cooper-Frye sampler
- Particlization of fluid elements

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**SMASH**
- Hadronic transport approach
- Evolution of the late hadronic rescattering stage

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- Weil et al.: PRC 94 (2016)
Why another hybrid approach?

- Baryon stopping is important for the description of heavy-ion collisions at NA61/SHINE, BES and GSI/FAIR energies
- SMASH is capable of describing proton rapidity spectra across a wide range of collision energies
- Apply SMASH for the initial and final state in a novel hybrid model

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Further Results

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Exploring the high baryon-density regime of the QCD phase diagram within a novel hybrid approach

arXiv: 2112.08724
Validation

Anna Schäfer, Iurii Karpenko, Hannah Elfner

Energy, baryon number, and electric charge globally conserved in full SMASH-vHLLE-hybrid run

Violations < 7%

E, B, and Q gain and loss stem from finite grid effects in the hydrodynamic stage

Freezeout diagram of central Au+Au/Pb+Pb collisions between √s = 4.3 GeV and √s = 200.0 GeV

Obtained in final stage of hydrodynamical evolution, before hadronic rescatterings are carried out

Parametrization of freezeout curve (Cleymans et al.) deduced from experimentally measured hadron abundances in the final state (that is after rescattering)

Shape of freezeout curve obtained with SMASH-vHLLE-hybrid qualitatively similar to parametrization (perfect agreement is not expected)

⇒ Freezeout hypersurface is characterized with reasonable properties


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