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

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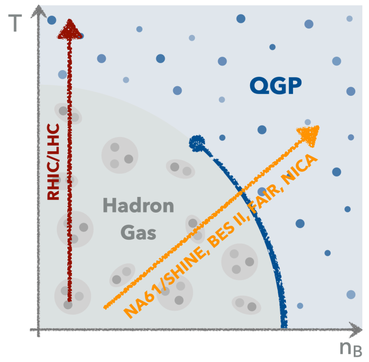
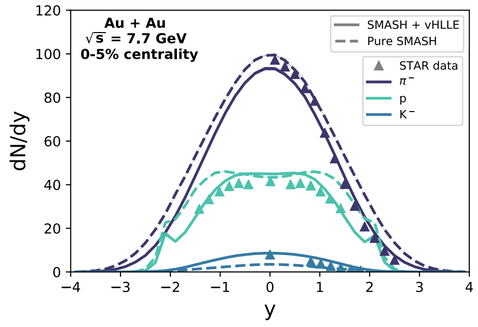
Motivation and Model Description

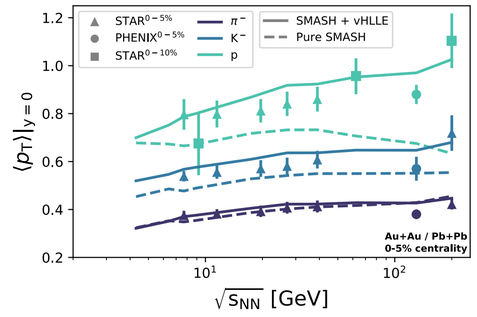
- Heavy-ion collisions at intermediate collision energies have become of interest to study the QCD first order phase transition and critical end point
- Experimentally covered by NA61/SHINE, BES II as well as future FAIR and NICA



- 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

Outlook

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

[1] Weil et al.: Phys. Rev. C 94 (2016) no.5, 054905
[2] Karpenko et al.: Comput. Phys. Commun. 185 (2014), 3016-3027
[3]Akamatsu et al.: Phys. Rev. C 98 (2018) no.2, 024909

The SMASH-vHLLE-Hybrid

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Initial Conditions

- Propagate particles and perform interactions until hypersurface of constant proper time is crossed
- τ_0: geometrical interpretation of the passing time of the two nuclei, but enforcing $\tau_0 \geq 0.5$ fm
- $\tau_0 = (R_p + R_t) \Big/ \sqrt{\left(\sqrt{s_{\mathrm{NN}}}/(2\ m_{\mathrm{N}})\right)^2 - 1}$

Evolution of the hot and dense fireball

- Quark gluon phase is evolved according to chiral model EoS
- Particlization on hypersurface of constant energy density: $e_{crit} = 0.5$ GeV/fm^3
- Particlization according to SMASH HRG EoS

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

+

SMASH

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

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Weil et al.: PRC 94 (2016)
Huovinen et al.: Eur. Phys. J A 48 (2012)
Karpenko et al.: PRC 91, 064901 (2015)
Cooper and Frye: Phys.Rev.D 10 (1974)
Karpenko et al.: Comput. Phys. Commun. 185 (2014)

Why another hybrid approach?

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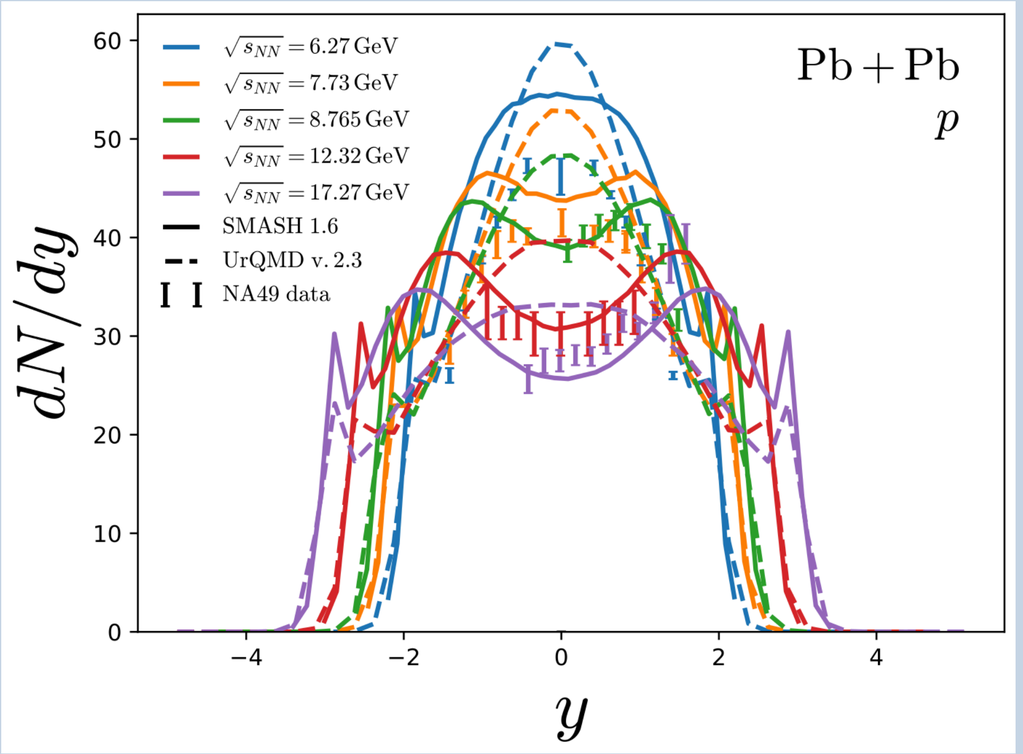
- Baryon stopping is important for the description of heavy-ion collisions at NA61/SHINE, BES and GSI/FAIR energies
- SMASH is capable of describing proton rapidity spectra across a wide range of collision energies
- Apply SMASH for the initial and final state in a novel hybrid model



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Mohs et al.: J.Phys.G 47 (2020)

Further Results

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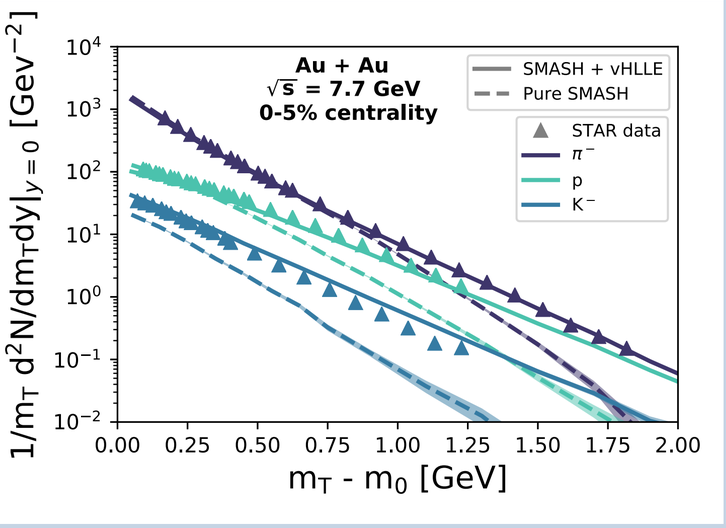

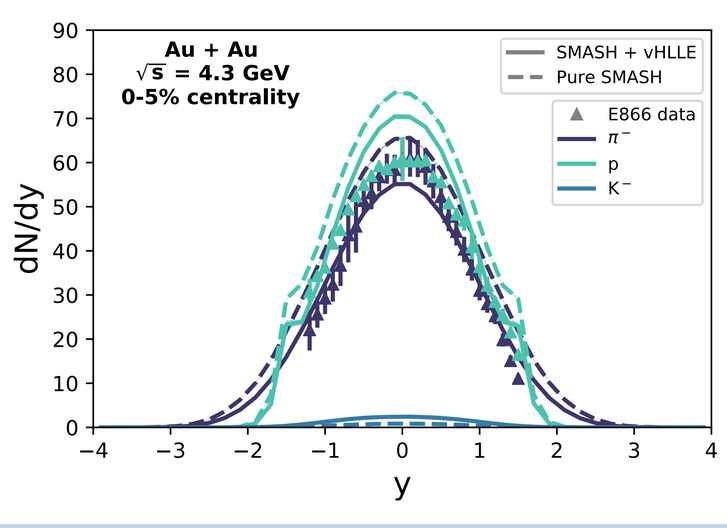

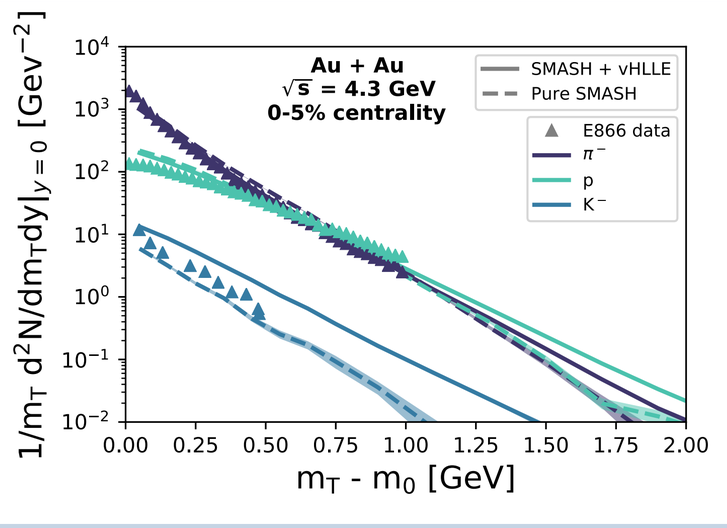

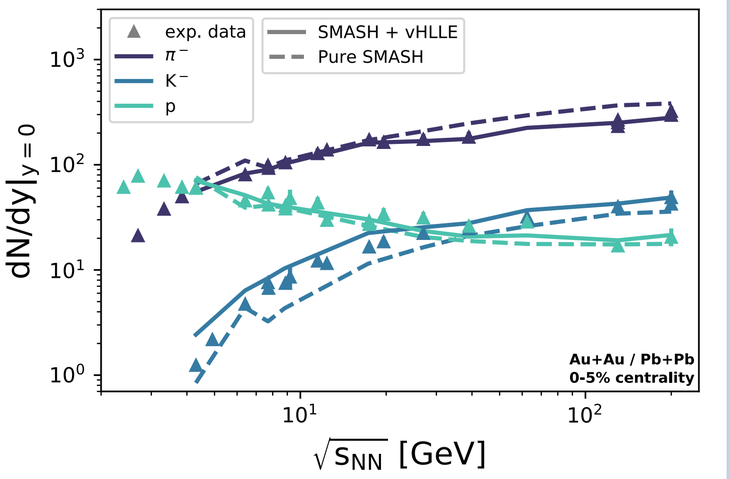

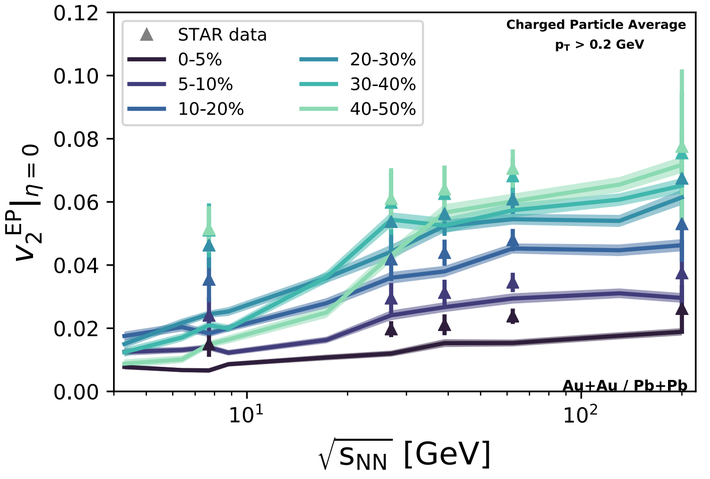

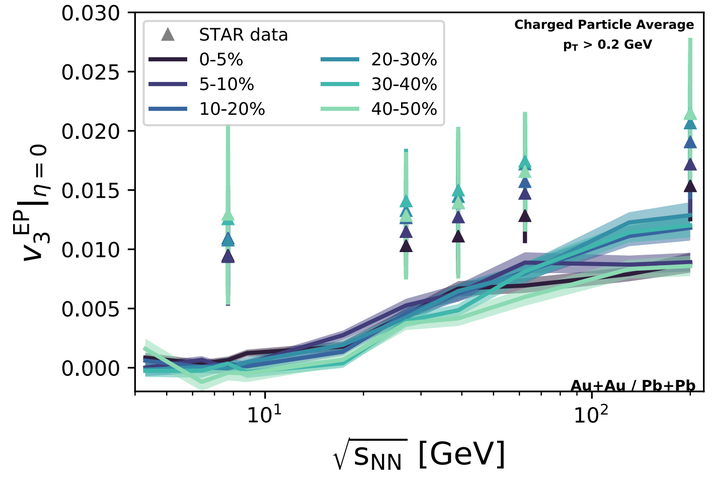

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Validation

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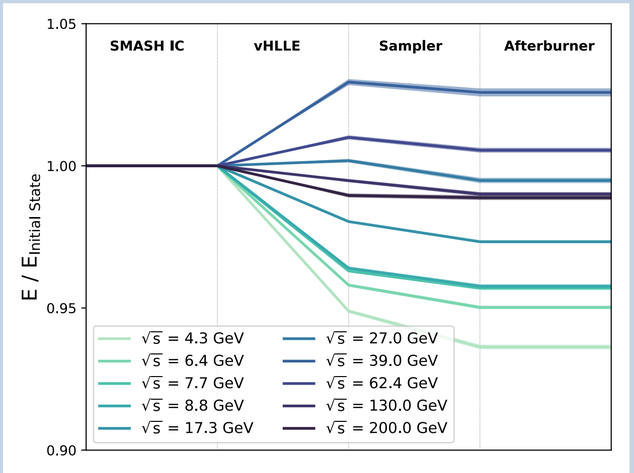
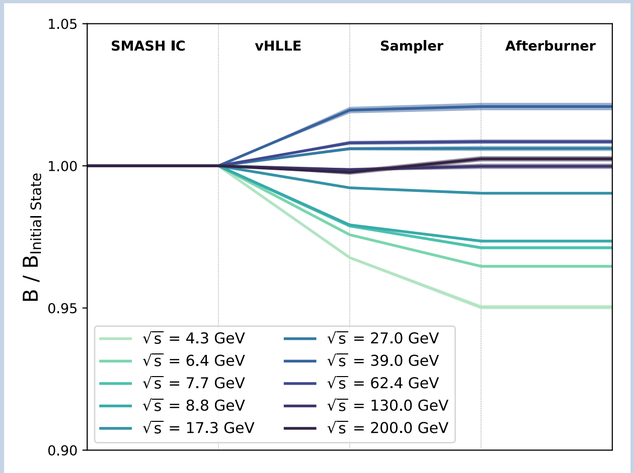
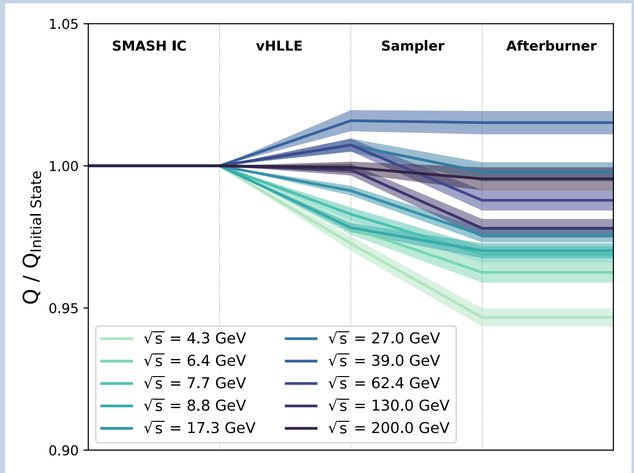
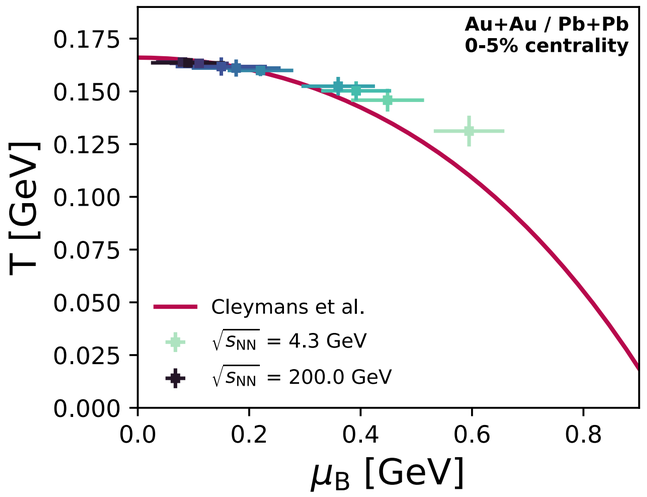






- Energy, baryon number, and electric charge globally conserved in full SMASH-vHLLE-hybrid run
- Violations < 7%
- E, B, and Q gain and loss stem from finite grid effects in the hydrodynamic stage



- 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

Cleymans et al.: PRL 81 (1998)
Cleymans et al.: J.Phys.G 32 (2006)

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