Entropy Production and Reheating at the Chiral Phase Transition

C. Herold , **A. Kittiratpattana**, C. Kobdaj, A. Limphirat, Y. Yan, M. Nahrgang, J. Steinheimer and M. Bleicher

FIAS Frankfurt Institute for Advanced Studies

We study the production of entropy in the context of a nonequilibrium chiral phase transition. The dynamical symmetry breaking is modeled by a Langevin equation for the order parameter coupled to the Bjorken dynamics of a quark plasma. We investigate the impact of dissipation and noise on the entropy and explore the possibility of reheating for crossover and first-order phase transitions, depending on the expansion rate of the fluid. The relative increase in is estimated to range from 10% for a crossover to 100% for a first-order phase transition at low beam energies, which could be detected in the pion-to-proton ratio as a function of beam energy.

I. Motivation

- Entropy production for characteristic signal for a critical point (CP).

II. Chiral Bjorken Dynamics

- Our ansatz

$$\mathcal{L} = \bar{q}\left(i\gamma^{\mu}\partial_{\mu} - g\sigma\right)q + \frac{1}{2}\left(\partial_{\mu}\sigma\right)^{2} - U(\sigma),$$

$$U(\sigma) = \frac{\lambda}{4}(\sigma^{2} - f_{\pi}^{2})^{2} - f_{\pi}m_{\pi}^{2}\sigma + U_{0}.$$

- Langevin equation with dissipation η and stochastic noise ξ.

$$\ddot{\sigma} + \left(\frac{D}{\tau} + \eta\right)\dot{\sigma} + \frac{\delta\Omega}{\delta t} = \xi.$$

- Bjorken hydrodynamics (t, z)
  - The quark Ideal fluid
    - $T_{q}^{\mu\nu} = \partial_{\mu}(e+p)u^{\mu}u^{\nu} - pg^{\mu\nu}$,

$$\partial_{\mu}T_{q}^{\mu\nu} = \partial_{\mu}T_{\sigma}^{\mu\nu}$$

  - $\dot{e}$, $\dot{n}$ and $p = -\Omega_{q\bar{q}}$ can be acquired.
  - The entropy density

$$s(\tau) = \frac{e + p - \mu n}{T}$$

III. Result on Entropy production

- The evolution from various (T, μ). (Figure 1)
- The relative total entropy S/S_0 (Figure 2).
  - **FOPT → more than $20 - 200\%$**
  - **CP → around 20%**
  - **CO → less than 20%**

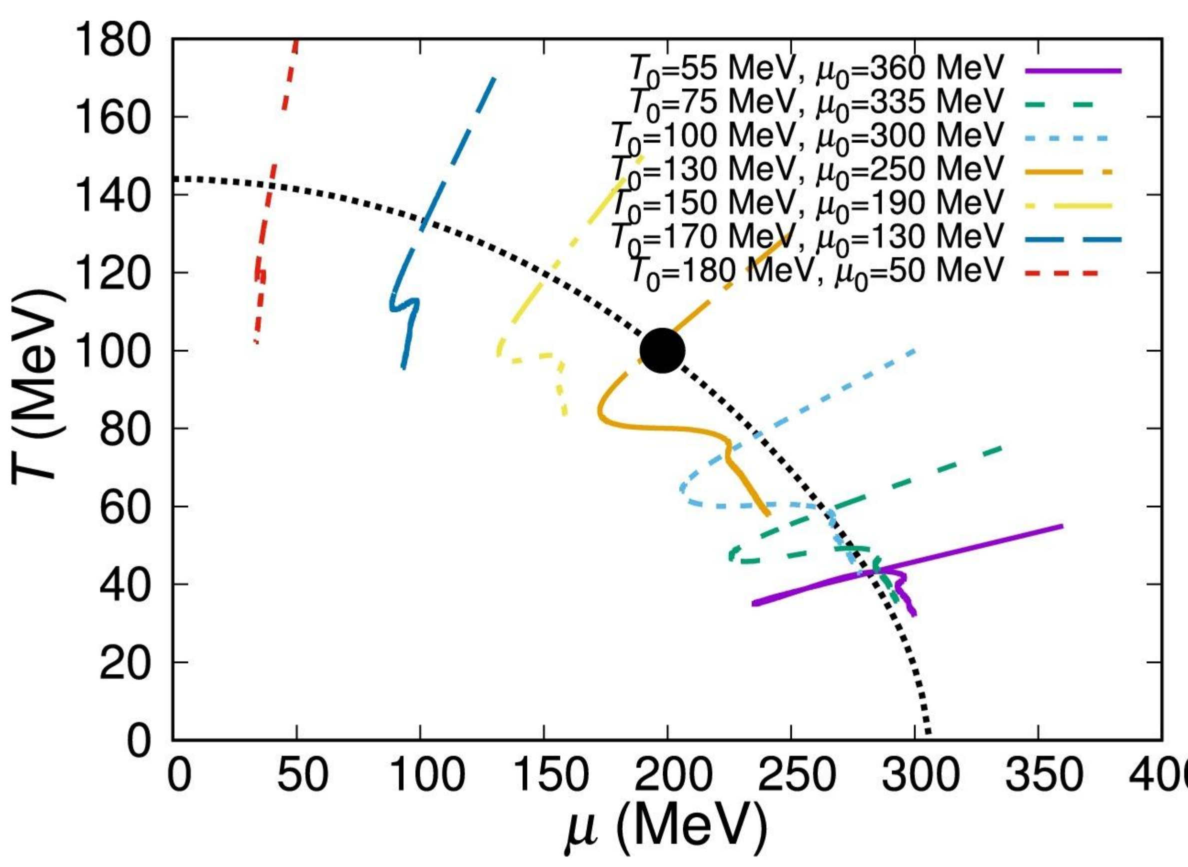

Figure 1: Event-averaged trajectories for several initial conditions, probing different regions of the phase diagram. The dashed line corresponds to the phase boundary and the black dot represents the position of the CP.

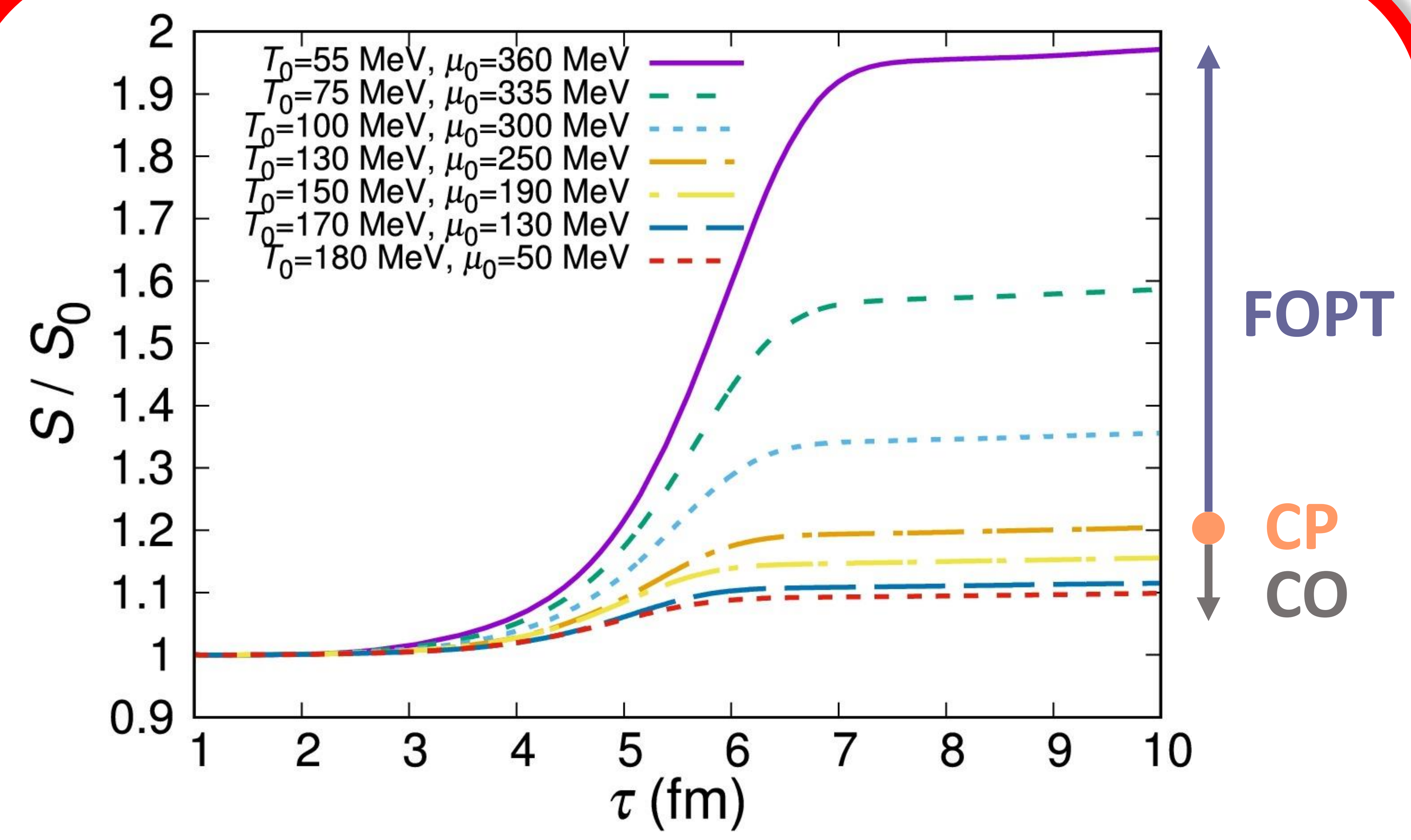

Figure 2. Relative entropy increase corresponds to the trajectories in Fig. 1

a. Dissipation and Noise

- The dissipation η gives a proper relaxation of σ.
- The rapid increase of $\Delta\sigma$ is the effect from the rapid change of Temperature
- The entropy increases by both η and ξ.

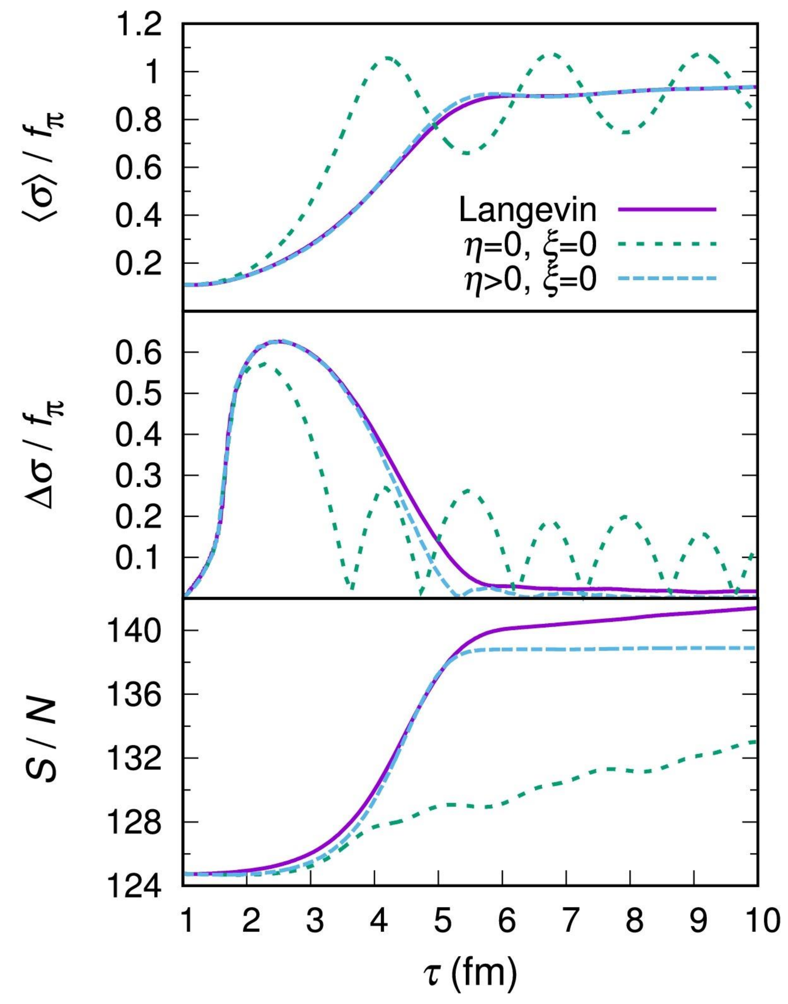

Figure 3. The effects of dissipation and noise

b. Reheating

- The reheating strength & entropy production.
- An impact of the expansion rate.

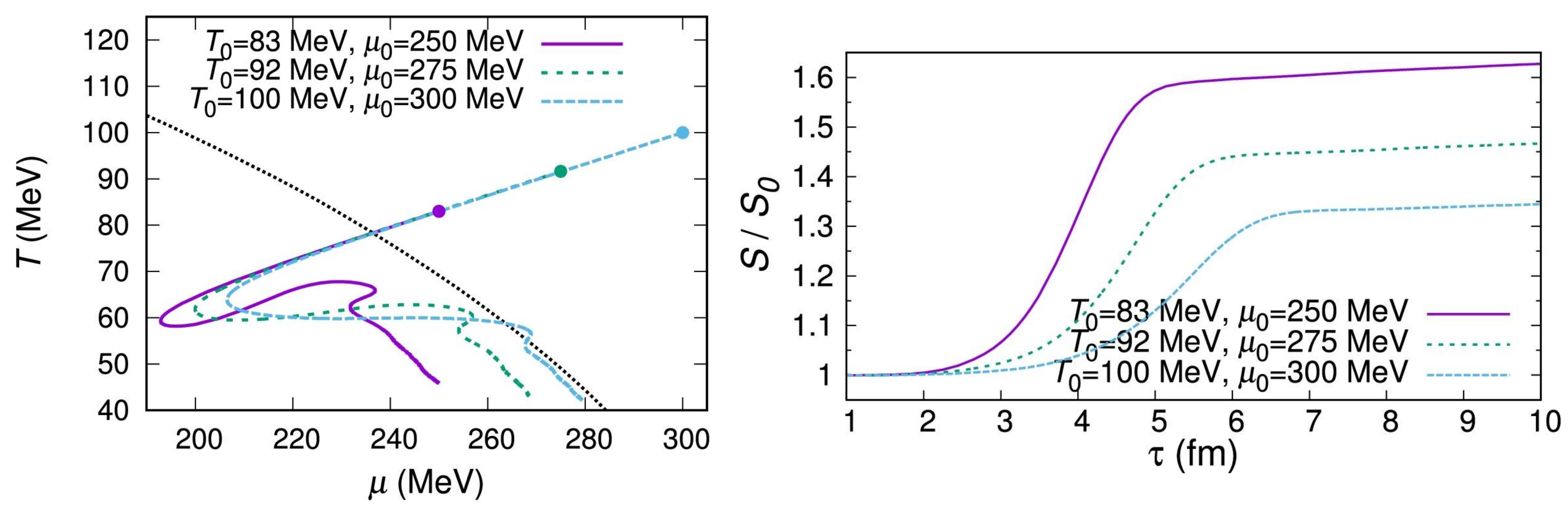

Figure 4. Left: The trajectories on the same isentropic line with different distances. Right: Entropy increase corresponds to the trajectories.

IV. Conclusion

- π/p ratio as a function of beam energy.
- Inhomogeneous 3+1 full dynamics will be studied (the effect of spatial fluctuations)

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Suranaree University of Technology, Thailand
apiwitkitti@g.sut.ac.th

For more information