Constraining baryon annihilation in the hadronic phase of heavy-ion collisions via event-by-event fluctuations

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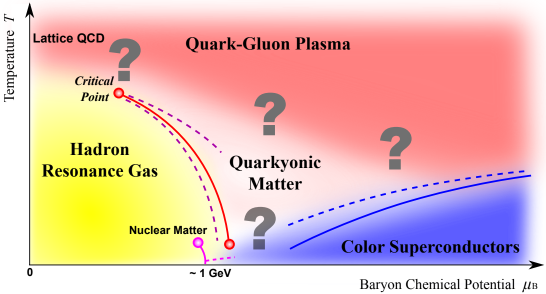
[Phys. Lett. B 827, 136983 (2022)]

Thx to V.Vovchenko, R.Poberezhnyuk, V.Kuznietsov, J.Steinheimer, M.Gorenstein, V.Koch, H.Stoecker

Outline

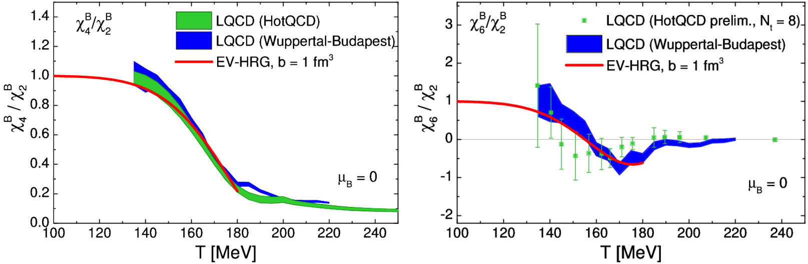
QCD phase diagram



[K. Fukushima, T.Hatsuda: Rept.Prog.Phys.74,2011]

- Crossover from hadron-resonance gas (HRG) to quark-gluon plasma (QGP) at high temperature and low density
- Hypothetical first order phase transition HRG-QGP at finite baryochemical potential with critical endpoint
- Liquid-gas phase transition with critical point at $T \approx 18\ MeV$, $\mu_B \approx 900\ MeV$
- More exotic states for finite μ_Q and μ_S

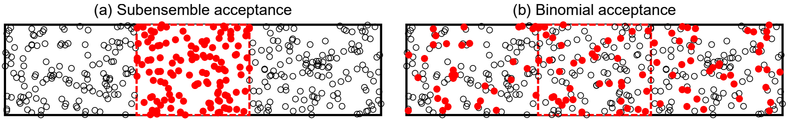
Lattice Susceptibilities



- Cooper-Frye produces Poissonian fluctuations of particles on freeze-out. This is valid for ideal hadron resonance gas.
- The Excluded Volume model used in procedure gives a **good approximation of lattice susceptibilities**.[V. Vovchenko, V. Koch, Phys. Rev. C 103, 044903]
- Red line is the input we use.
- **Cumulants change during the hadronic phase?**. This evolution can depend on different assumptions.

Subensemble procedure

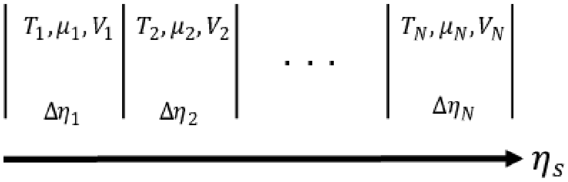
$$Z(T,V,B) = \sum_{B_1} Z(T,\alpha V,B_1) Z(T,(1-\alpha)V,B-B_1)$$



A subsystem (dashed red rectangle) within a thermal system (solid black rectangle). The subsystem can exchange particles (conserved charges), shown by the circles, with the rest of the system. The filled red circles in (a) depict the particles within the subsystem, as considered in the present subensemble acceptance method (SAM). In contrast, the filled red circles in (b) highlight the particles from a typical configuration resulting from the binomial filter.

[V. Vovchenko, **O.S**, R.Poberezhnyuk, M. Gorenstein, V. Koch, Phys. Lett. B 811, 135868 (2020)]

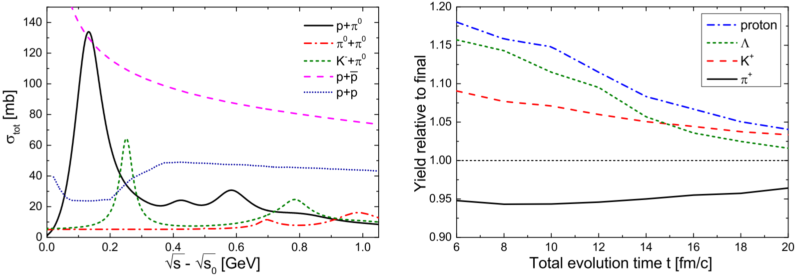
EV Sampler



[V. Vovchenko, V. Koch, Phys. Rev. C 103, 044903]

- The particle numbers are sampled accordingly to the grand canonical partition function in 96 cells distributed in space time rapidity $-4.8 \leq \eta \leq 4.8$, $\Delta\eta = 0.1$ units.
- The exact **baryon number conservation** is ensured by accepting configurations with net baryon charge $\sum_{cell=1}^{96} (B_{cell} - \bar{B}_{cell}) = 0$.
- For each particle momentum is sampled according to the blast wave model. The rapidity used in sampling is the cell rapidity of the particle plus thermal smearing. Thus some particles leave η acceptance interval.

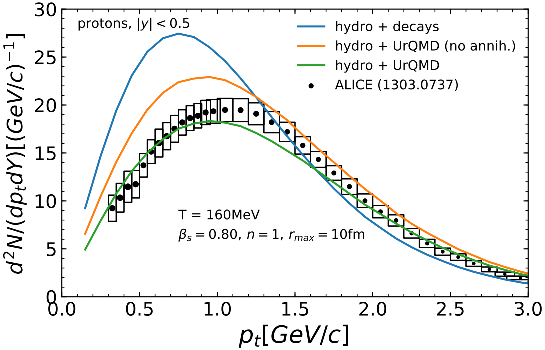
Hadronic Afterburner



[J. Steinheimer, J. Aichelin, M. Bleicher, H. Stöcker, Phys. Rev. Lett. 110, 042501]

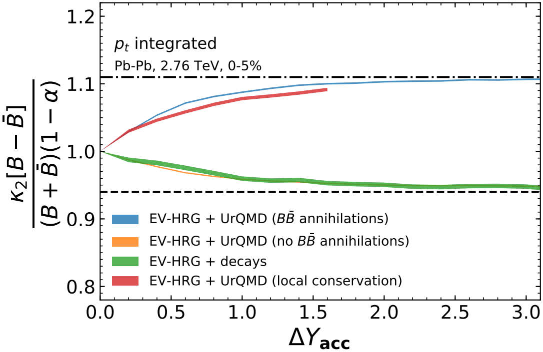
- After the hydrodynamic stage and freeze-out hadrons are propagated using transport model
- This hadronic phase modifies almost all bulk observables compared to freeze-out
- Baryon annihilations crossection is large. Most annihilations happen into several particles, e.g. $p\bar{p} \to N\pi, \langle N \rangle = 5$. Most transport codes (including UrQMD) do not include inverse reactions thus breaking detailed balance.

Proton Spectra



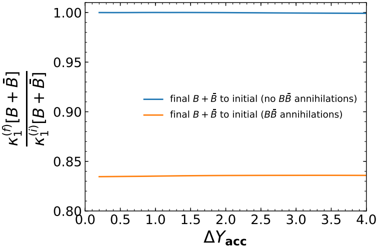
- Freeze-out hypersurface is taken from [Huovinen et al. Phys.Lett.B769, 2017].
- The analysis in that paper used pion spectra that is almost unchanged in the Afterburner.
- Leads to satisfactory description of proton spectra that is sensitive to the Afterburner.

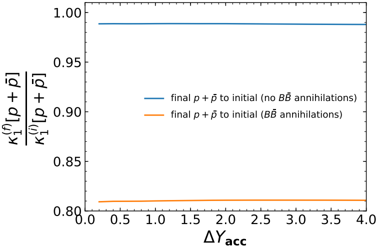
Variance of net baryon number

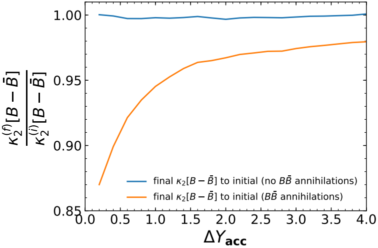


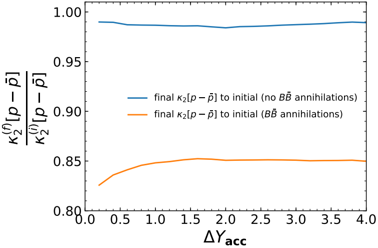
- $|y| < \Delta Y_{max}/2$
- The results are divided by $1-\alpha$ factor to correct them for baryon number conservation.
- The dashed line corresponds to the grand-canonical EV-HRG value $\kappa_2[B-\bar{B}]/B+\bar{B} \simeq 0.94$.

Effects of the afterburner

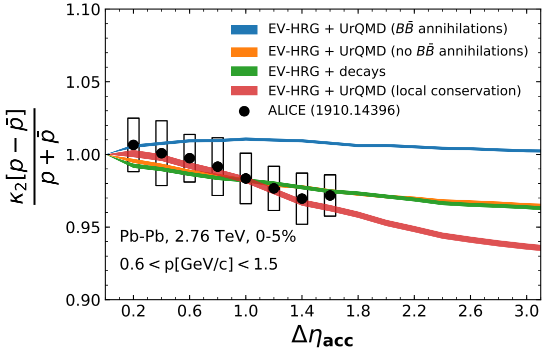






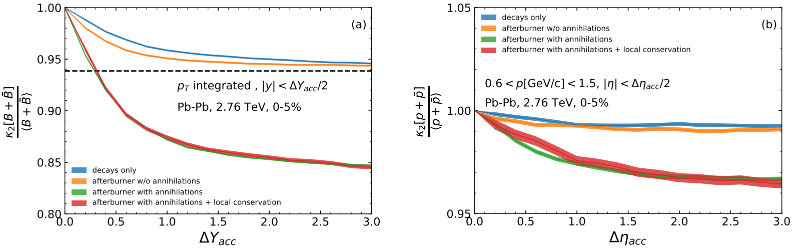


Net proton number



- The experimental data [ALICE@CERN, Phys.Lett.B807, 2020].
- No annihilation and local conservation scenarious are within error bars.

Local conservation or regeneration?



(a) Rapidity acceptance dependence of net baryon $B = \kappa_2[B + \bar{B}]/B + \bar{B}$ in 0-5% central Pb-Pb collisions at the LHC.
(b) The calculations shown in this figure are not corrected for volume fluctuations.

Conclusions

- Measurements of event-by-event fluctuations in heavy-ion collisions can be used to quantify the effect of baryon annihilation in the hadronic phase.
- Either, baryons are completely regenerated and baryon number is conserved only globally or, the mean baryon number is reduced due to annihilation which requires a more local conservation of the baryon number.
- To distinguish the different possibilities we suggest a new observable: the scaled variance of the number of protons + anti-protons, which shows a clearly distinguished dependence on annihilation and local conservation.

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Thank you for attention!