Effect of the QCD equation of state and strange hadronic resonances on multiparticle correlations in heavy ion collisions (nucl-th/1711.05207)


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Why do we need additional strange resonances?

- Additional resonances are needed in order to reproduce Lattice QCD (LQCD) results on partial pressures $p^T$ [1, 2].
- In the Hadron Resonance Gas model (HRG) the total pressure is given by the contributions from each hadron family with baryon number $B$ and strangeness content $S$.

$$P(\mu_B, \mu_S) = \sum_{\text{hadrons}} P_B^S = P_M^S + \mu_B^S \cosh(\mu_B) + \mu_S^S \cosh(-\mu_S)$$

- Comparison of partial pressures $p^T$ from Wuppertal-Budapest LQCD collaboration and Hadron Resonance Gas (HRG) model using PDG2016 with only $****$ states [3] need for additional strange states.
- Hypertens in the $S = -1$ (e.g. $\Lambda$) and $S = -2$ sector (e.g. $\Xi$), are underestimated.

- PDG16 most up-to-date list of all $***$ states from the Particle Data Group.
- PDG16+ most up-to-date list of all $****$ states from the Particle Data Group.
- Only strong decays with non negligible branching ratios ($\approx 1\%$ or higher).
- If branching ratios do not sum to 100% remaining decays $N_2 \rightarrow N_2 + N_3$ where $N_2$ and $N_3$ are hadrons with the same quantum numbers and $N_2$ is the next state in descending mass order with parity compatible for such a decay.
- If no decay information available then $\leq 30\%$ BR hadronic decays, $\geq 70\%$ radiative decays.

To leading order in the baryochemical potential $\mu_B$, the ratio $\mu_S/\mu_B$ reads:

$$\left(\frac{\mu_S}{\mu_B}\right)_{\text{LO}} = \frac{x_0^{\text{HS}}}{x_0^{\text{LO}}} \frac{x_1^{\text{HS}}}{x_1^{\text{LO}}} \frac{x_2^{\text{HS}}}{x_2^{\text{LO}}}$$

Extremely sensitive to the amount of heavy strange and charged particles in the hadronic spectrum.

Additional strange states in PDG2016+ the agreement with LQCD up to $T = 145$ MeV.

Lattice QCD based Equation of State

The Equation of State (EoS) is the fundamental input to the hadronic evolution and therefore we must test the effect of the assumptions on the number of thermalized quarks.

- $T < 153$ MeV $\rightarrow$ HRG with PDG16+.

The hydrodynamical modeling

The parameterization for switching on/off of the hydrodynamical evolution has been chosen to be as consistent as possible with LQCD results.

Event-by-event viscous hydrodynamics + USPHydro [6] with TRENTINO initial conditions [7], assuming $T_{\text{ini}} = T_{\text{PDG}}$.

For the simulations both at RHIC Au-Au 200 GeV and ALICE Pb-Pb 5.02 TeV the hydrodynamics description is switched on at $\tau_0 = 0.6$ fm and the hadrons are formed at $T_{\text{sp}} = 150$ MeV.

Results

Effects of the additional resonances on particle spectra and $<p_T>$

- Enhancement of $p$ and $K$ spectra at higher $p_T$ for $2+1$ EoS.
- Inclusion of charm quarks $\rightarrow$ less production of high $p_T$ particles.
- Inclusion of extra resonances $\rightarrow$ larger $p_T$.
- Inclusion of charm quarks $\rightarrow$ smaller $<p_T>$.
- Up to intermediate centrality range.
- Increase of $+$ states $\rightarrow$ increase of $<p_T>$.

The shear viscosity $\eta/s$ has been extracted from the comparison of our theoretical results obtained with different EoS to flow harmonics $v_2$ [2], $v_3$ [2] obtained from STAR in Au-Au 200 GeV [8] and LHC run2 Pb-Pb 5.02 TeV [9].

- At RHIC energies all three EoS describe the data quite well $\rightarrow$ no dependence on the chosen EoS, agreement with previous results based on Bayesian analysis [10].
- Normalized charm quarks $\rightarrow$ smaller $\eta/s$ with respect to the 2+1 EoS.
- Higher temperatures probed at LHC run 2 (up to $T = 600$ MeV) splitting between the $2+1$ and $2+1+1$ states $\rightarrow$ different values of $\eta/s$.

Conclusions

- EoS obtained by matching the state-of-the-art LQCD calculations for $2+1/2+1+1$ quark flavors to a HRG model based PDG2016+ spectrum containing extra resonances relevant for reproducing lattice data on partial pressures.
- The inclusion of additional $****$ states:
  - Increase the agreement with LQCD data up to $T = 145$ MeV, close to the crossover region.
  - Enhance the production of particles at higher $p_T$ and lead to a higher $<p_T>$.
  - Results for all three EoS obtained at RHIC energies are in agreement with previous Bayesian analyses.
- $\eta/s$ ratio at LHC run2 energies depends on the EoS and there is roughly a 15% difference in $2+1$ and $2+1+1$ EoS results which should increase at higher temperatures.

References