Cross-correlators of conserved charges in QCD

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Based on arXiv:

Premise: Cross-correlators in QCD

Fluctuations and correlations of conserved charges BQS are **derivatives of the pressure with respect to the chemical potential(s)**:

$$\chi^{BQS}_{ijk}(T,\hat{\mu}_B,\hat{\mu}_Q,\hat{\mu}_S) = \frac{\partial^{i+j+k}\left(p\left(T,\hat{\mu}_B,\hat{\mu}_Q,\hat{\mu}_S\right)/T^4\right)}{\partial\hat{\mu}_B^i\partial\hat{\mu}_Q^j\partial\hat{\mu}_S^k}$$

They provide a great tool for studying chemical freeze-out in heavy ion collisions (HIC) because:

I. **They can be calculated in equilibrium with lattice QCD**

II. **They are closely related to experimentally measured particle fluctuations and correlations**

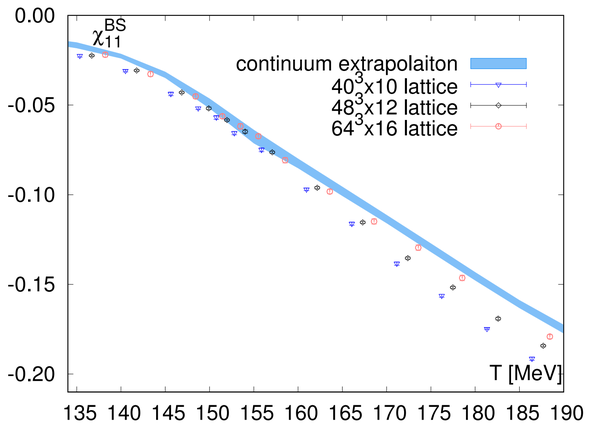
To directly compare lattice and experiment, there are obstacles, e.g.

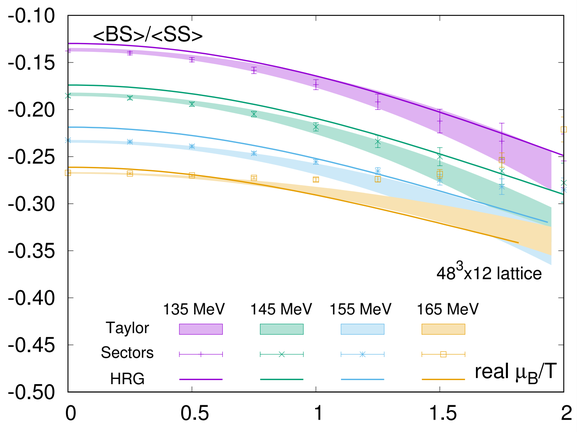
* **Resonance decays feed-down** [1]
* **Cuts on the kinematics** [2]
* **Correlations of BQS $\neq$ correlations of hadrons!**

} **Hadron Resonance Gas (HRG) model**

I. From the lattice: BQS correlators

* **Continuum extrapolation** of χ^{BS}_{11} (left panel) at $\mu_B = 0$
* **Extrapolation** of $\chi^{BS}_{11}/\chi^{S}_{2}$ **to real** $\mu_\mathbf{B}/\mathbf{T}$ on a $48^3 \times 12$ lattice (right panel)





II. The bridge to experiment: HRG model

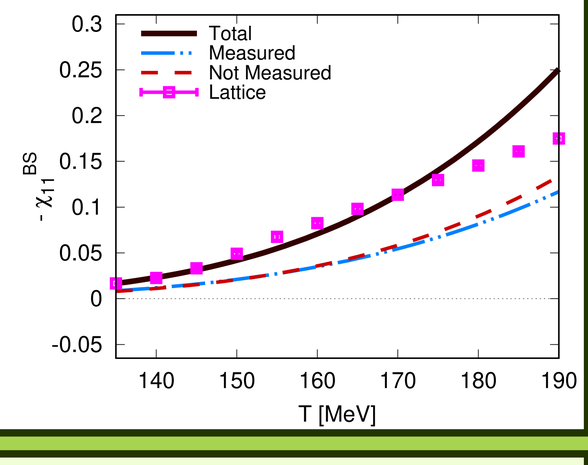
The HRG model allows us to study fluctuations and cross-correlators:

i. **Including the effects mentioned above**
ii. **Considering the contributions from different hadrons**
iii. **Accounting for which particles can/can't be measured!**

We consider the following as the **commonly measured species**:

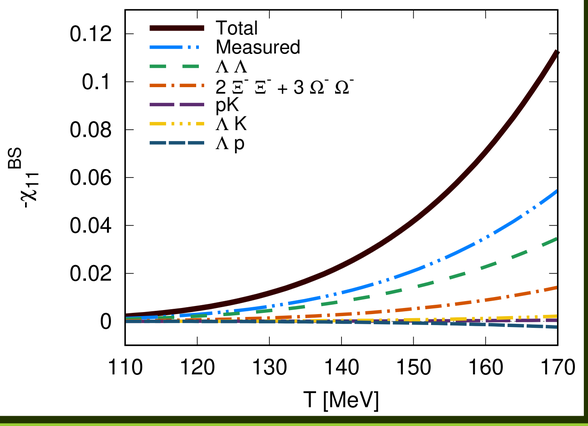
$$\pi^{\pm},\ K^{\pm},\ p\,(\overline{p})\,,\ \Lambda(\overline{\Lambda}),\ \Xi^{-}(\overline{\Xi}^{+}),\ \Omega^{-}(\overline{\Omega}^{+})$$

* Split cross-correlators **into measured and non-measured parts**
* **Plot:** χ^{BS}_{11} at $\mu_B = 0$ from lattice QCD and HRG model (measured and non-measured)
* **NOTE:** A sizable share is carried by particles which cannot be measured!



III. Break down the contributions

* Each observable receives contributions from different hadronic (self) correlators
* We break down **how much each correlator contributes to a certain observable**
* Notably, **correlators between different species are negligible**

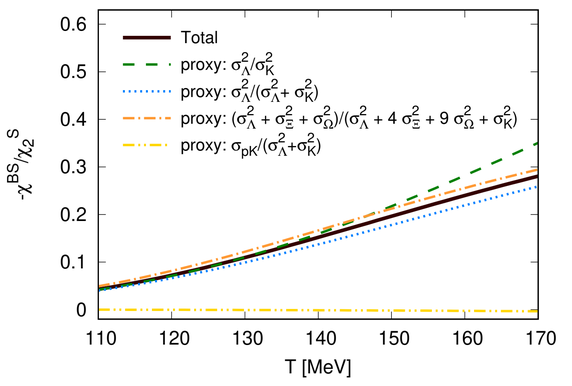


IV. Build hadronic proxies

In order to eliminate volume effects (to first approximation), we need to **consider ratios of correlators** ($\chi^{BS}_{11}/\chi^{S}_{2}$ in the plot)

* Can we reproduce a ratio of conserved charges correlators **using measured hadronic fluctuations**?
* The main contribution to χ^{BS}_{11} is the net-Λ variance, then we build for the ratio $\chi^{BS}_{11}/\chi^{S}_{2}$ the proxy:

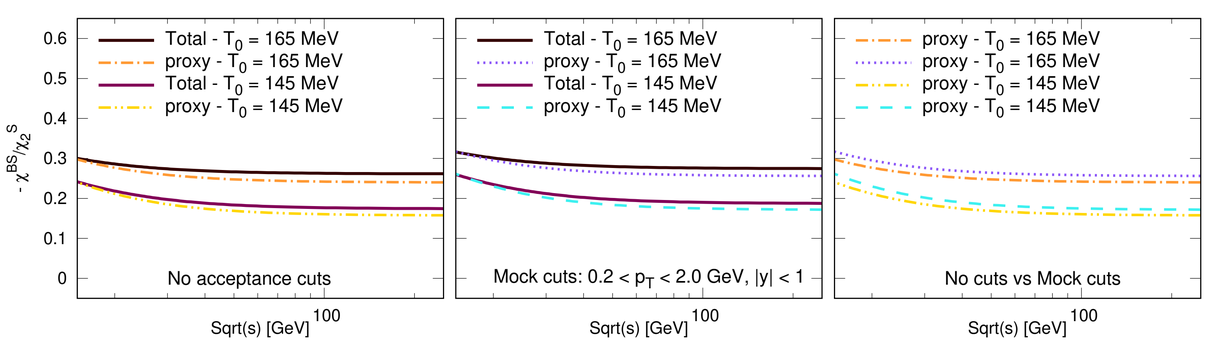
$$\boxed{\widetilde{C}^{\Lambda,\Lambda K}_{BS,SS} = \sigma^2_\Lambda/(\sigma^2_K + \sigma^2_\Lambda)}$$



The proxy is within 10% of the total ratio for all temperatures

V. Finite μ_B and kinematic cuts

* We analyze the behavior of the proxy at finite μ_B (left panel), along two parametrized freeze-out lines with $T(\mu_B = 0) = 145, 165\,\mathrm{MeV}$
* We consider the effect of cuts on the kinematics (central panel)
* We examine the difference between cuts and no cuts (right panel)



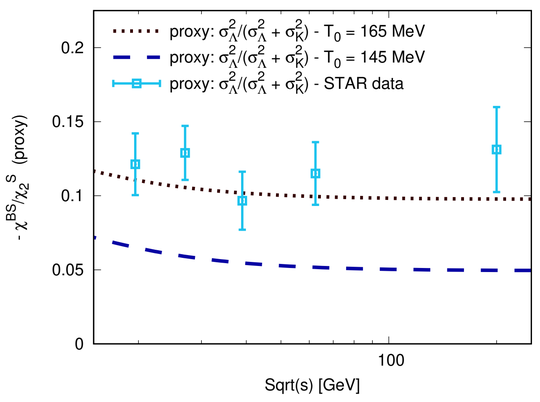
And we can conclude that:

1. **The proxy works at finite μ_B as well**
2. **The proxy works when kinematic cuts are included too**
3. **The dependence on the cuts is minimal**

VI. Comparing to experiment

Can we compare lattice and experiment now? Not yet!

* In the previous plot (central panel) **the same cuts were applied to both Λ and K**
* We now **compare our proxy** to preliminary STAR data, where the cuts on Λ and K are different [3, 4]
* This observable seems to **favor a higher freeze-out temperature**, at the limit of applicability of the HRG model



NOTE: including different cuts for Λ and K results in a factor ~ 3 difference (compare central panel in **V.** with **VI.**)

Conclusions

- A good proxy for $\chi^{BS}_{11}/\chi^{S}_{2}$ can be build with σ^2_Λ and σ^2_K only , which **works at finite μ_B and has small cut dependence**
- Correlators of different hadrons are negligible, and multi-strange baryons are not necessary for this ratio
- **Direct comparison of lattice and experiment is not yet possible**, as the same cuts need to be applied to all species
- Our strangeness-based proxy suggests a **higher freeze-out temperature** than the light-flavor-dominated ratios in [2]

References

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[4] T. Nonaka [STAR Collaboration], Nucl. Phys. A **982** (2019) 863