Testing new proxies for B,Q & S cumulants in Au+Au collisions at BES energies with EPOS 4

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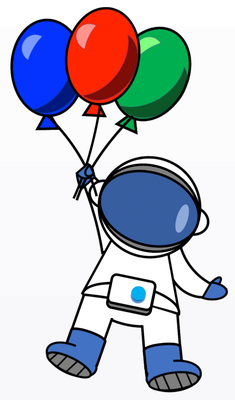

Introduction

In the exploration of the nuclear matter phase diagram, the susceptibilities of conserved charges are useful theoretical tools to probe the existence of a 1st order phase transition, and a possible critical endpoint. They can be related to the cumulants of conserved charges like baryon number B, electric charge Q and strangeness S, for which experimental proxies are measured in heavy-ion collisions (HICs) via cumulants of net-number of hadronic species.

It is nevertheless important to evaluate how good those proxies are at estimating the ratios of corresponding conserved charge susceptibilities. For this reason, we studied the impact of hadronic cascades on some of those observables measured by the STAR collaboration, thanks to Au+Au collision simulations performed with EPOS4. These results are compared with cumulant ratios of conserved charges. Alternative proxy ratios are also proposed to better reconstruct the latter.

Context & Motivation

The STAR collaboration has measured the following ratios, as proxies for the C_{QB}, C_{QS} and C_{BS} ratios respectively [1]:

$$C_{Qp} = \frac{\sigma^{11}_{Qp}}{\sigma^2_p}\left(\cong \frac{\chi^{QB}_{11}}{\chi^B_2}\right),\ C_{QK} = \frac{\sigma^{11}_{QK}}{\sigma^2_K}\left(\cong \frac{\chi^{QS}_{11}}{\chi^S_2}\right),\ C_{pK} = \frac{\sigma^{11}_{pK}}{\sigma^2_K}\left(\cong \frac{\chi^{BS}_{11}}{\chi^S_2}\right),$$

for Au+Au collisions in the whole energy range of the Beam Energy Scan phase I (BES-I) program, *i.e.* $\sqrt{s_{NN}} = 7.7 - 200$ GeV/A.

Based on the study from [2] using the HRG model to evaluate the contribution from each hadronic species to the 2nd order susceptibilities of B, Q and S, we want to examine the following proxies:

$$\tilde{C}_{QB} = \frac{\sigma^{11}_{\pi p} + \sigma^2_p}{2\sigma^2_p + \sigma^2_\Lambda} \quad , \quad \tilde{C}_{QS} = \frac{1}{2}\cdot\frac{\sigma^2_K}{\sigma^2_K + \sigma^2_\Lambda} \quad , \quad \tilde{C}_{BS} = \frac{\sigma^2_\Lambda}{\sigma^2_K + \sigma^2_\Lambda}$$

as potential better proxies than the respective ones used by STAR.

While $\tilde{C}_{QS}$ and $\tilde{C}_{BS}$ are proposed in [2], we propose the new proxy ratio $\tilde{C}_{QB}$ [3] based on the 2 arguments that:

- isospin randomisation (caused by reactions $p+\pi^{0/-} \leftrightarrow \Delta^{+/0} \leftrightarrow n+\pi^{0/+}$) does affect σ^2_p alone, but not $\sigma^{11}_{\pi p} + \sigma^2_p$
- isospin randomisation leads to the relation $\sigma^2_N \approx 2 \times \sigma^2_p$

Simulations & analysis method

Au+Au collisions are simulated at several energies of the BES-I program using EPOS4, a hybrid multi-purpose event generator. It relies on viscous relativistic hydrodynamics to model the evolution of the bulk matter, based on a full crossover equation of state for this work, a microcanonical hadronisation method [4], and uses UrQMD [5] as an afterburner.

The number of events simulated per collision energy, down to 19.6 GeV/A which is the lower limit of applicability for EPOS4, is given in Table 1.

$\sqrt{s_{NN}}$ (GeV/A)	19.6	27	39	62.4	200
N_{evts} (0-5%)	125k	125k	125k	100k	75k

Table 1: Total number of individual 0-5% events simulated with EPOS4 per collision energy.

The results shown on this poster are obtained:

- using STAR kinematic cuts, *i.e.* $|\eta| < 0.5$ and $0.4 < p_T < 1.6$ GeV
- by ignoring weak decays for conserved charge cumulants
- by using the DCA < 1 cm trigger method [1] for hadronic species

Acknowledgements

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References

[1] J. Adam et al. *Phys. Rev. C*, 100(1):014902, (2019). **[Erratum: Phys.Rev.C 105, 029901 (2022)]**.
[2] R. Bellwied et al. *Phys. Rev. D*, 101(3):034506, (2020).
[3] J. Jahan et al., paper in preparation. **[See PhD thesis: https://theses.hal.science/tel-04051507]**.
[4] K. Werner. Preprint arXiv:2306.10277, (2023).
[5] M. Bleicher et al. *J. Phys.*, G25:1859–1896, (1999).
[6] H. T. Ding, S. T. Li, Q. Shi, and X. D. Wang. *Eur. Phys. J. A*, 57(6):202, (2021).

Results - C_{QB}, C_{QS} and C_{BS} ratios & proxies

The C_{QB}, C_{QS} and C_{BS} ratios and their proxies, measured before the hadronic cascades (just after hadronisation) and in the final state, are shown in Figure 1 as functions of $\sqrt{s_{NN}}$ for 0-5% Au+Au collisions, along with the results of STAR proxies.

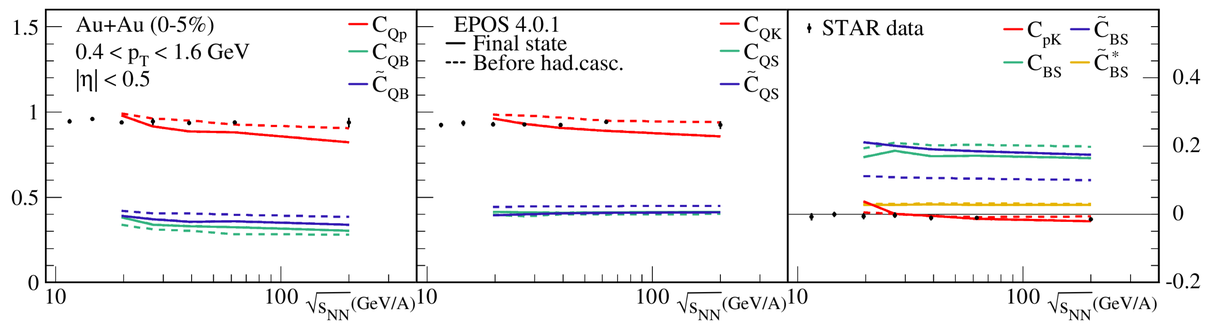

Figure 1: Energy dependence of C_{QB}, C_{QS}, C_{BS} and their proxies for central (0-5%) Au+Au collisions of the BES-I.

By comparing proxies with conserved charge cumulants, one observes that:

- **hadronic cascades do not affect** much **cumulant ratios**, except for the $\tilde{C}_{BS}$ proxy;
- the **new proxies better reproduce** the amplitude of the conserved charge cumulants **than STAR proxies**;
- although its magnitude is quite significantly modified by the hadronic cascades, $\tilde{C}_{BS}$ is a good proxy for C_{BS} since they have similar magnitude using particles after hadronic cascades;
- $\tilde{C}^*_{BS} = \sigma^2_\Xi/(\sigma^2_K + 4\sigma^2_\Xi)$, an alternative new proxy for C_{BS}, is less modified by the hadronic cascades than $\tilde{C}_{BS}$, but not as close to C_{BS} in magnitude though

A new probe for magnetic fields in HICs

A recent theoretical work based on (2+1)-flavour lattice QCD calculations with a background magnetic field suggested that the presence of the latter in HICs could be probed using the **ratio** $(2\chi^{QS}_{11} - \chi^{BS}_{11})/\chi^S_2$, which is shown to be **sensitive to the magnitude of** eB in the system [6].

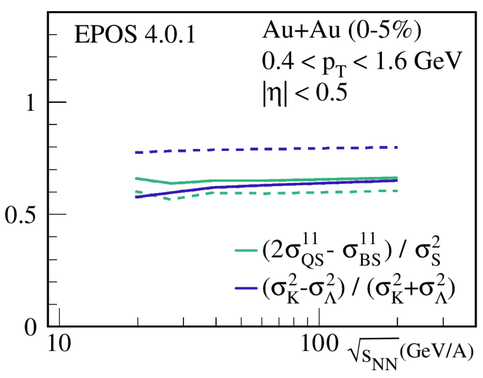

Figure 2: Energy dependence of $R^{e\mathcal{B}}_{K\Lambda}$ and $(2\chi^{QS}_{11} - \chi^{BS}_{11})/\chi^S_2$ ratio for central (0-5%) Au+Au collisions of the BES-I.

Based on the study presented previously, we propose $R^{e\mathcal{B}}_{K\Lambda}$ as a **new proxy** to evaluate experimentally this quantity:

$$R^{e\mathcal{B}}_{K\Lambda} = \frac{\sigma^2_K - \sigma^2_\Lambda}{\sigma^2_K + \sigma^2_\Lambda}\left(\cong \frac{2\chi^{QS}_{11} - \chi^{BS}_{11}}{\chi^S_2}\right).$$

As shown in Figure 2, it reproduces well the corresponding ratio of conserved charge cumulants in the final state. Further work would however be needed to determine the actual sensitivity of such probe to eB in realistic HIC simulations.

Summary

We have proposed the quantities $\tilde{C}_{QB}$, $\tilde{C}_{QS}$ and $\tilde{C}_{BS}$ as new proxies for ratios of 2nd order cumulants of conserved charges, implying σ^2_Λ in addition to the quantities used by STAR in their proxies. We have also proposed a new experimental proxy, $R^{e\mathcal{B}}_{K\Lambda}$, in order to probe the magnetic fields in HICs.