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Study of possible fluctuations of thermal parameters at freezeout using HRG model

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Abstract:

The extraction of thermal freezeout parameters from measured hadron yields and their higher moments have met with considerable success within the framework of hadron resonance gas models. The standard assumption in such studies is to consider a constant freezeout parameter set which is extracted by chi-square fit to data. The underlying assumption in such studies is that an ensemble of events belonging to a centrality class can be represented as a Grand Canonical ensemble (GCE). However, thermal conditions at freezeout need not be constant. They can fluctuate event by event as well as in the same event, there could be a distribution of temperatures and chemical potentials over freezeout hypersurface (FH). In this study we set up the framework to study fluctuations in thermal freezeout conditions of the former type. Understanding the nature of fluctuation of freezeout thermal parameters has significant implications on the ongoing searches for the QCD critical point.

1. Motivation

HRG framework is for a GCE. However, in experiments we obtain ensemble selected by centrality/multiplicity. How good is this a proxy for a GCE?

Fluctuation in thermal parameters could have varied origin:

- In a specific event, there could be hot and cold zones expanding at different rates over the FH, instead of a uniform thermal condition over the entire hypersurface
- Thermal conditions could also vary from event to event [1]. We address this scenario here.

2. Framework

- The logarithm of the total partition function for a multi component hadron gas at volume (V), temperature (T) and chemical potentials (μ_B, μ_S, μ_Q) corresponding to the QCD conserved charges is given by:

$$lnZ^{GC}(T,V,\{\mu_i\}) = \sum_i \frac{2g_iV}{(2\pi)^2}\sum_{k=1}^{\infty}(\pm1)^{k+1}\frac{e^{\beta\mu_i k}}{k}\frac{m_i^2}{\beta k}K_2(\beta k m_i) \quad (1)$$

$$N_i^{GC} = \frac{g_iV}{2\pi^2}\sum_{k=1}^{\infty}(\pm1)^{k+1}\frac{m_i^2 T}{k}K_2\left(\frac{km_i}{T}\right)e^{\beta\mu_i k} \quad (2)$$

where, $\mu_i = \mu_B B_i + \mu_S S_i + \mu_Q Q_i$ and +1(-1) for baryons (mesons)

- Instead of a single GCE, we replace it by a superposition of GCE's. We assume the simplest scenario where the fluctuation is parameterized by a Gaussian distribution.

$$N_i = B\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{g_iV}{2\pi^2}\sum_{k=1}^{\infty}(\pm1)^{k+1}\frac{m_i^2 T}{k}K_2\left(\frac{km_i}{T}\right)e^{\beta\mu_i k}\, e^{-\frac{(T-T_0)^2}{2\sigma_T^2}}\, e^{-\frac{\left(\mu_B-\langle\mu_B\rangle_0\right)^2}{2\sigma_{\mu B}^2}}\, dT\, d\mu_B \quad (3)$$

$$B^{-1} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} e^{-\frac{(T-T_0)^2}{2\sigma_T^2}}\, e^{-\frac{\left(\mu_B-\langle\mu_B\rangle_0\right)^2}{2\sigma_{\mu B}^2}}\, dT\, d\mu_B \quad (4)$$

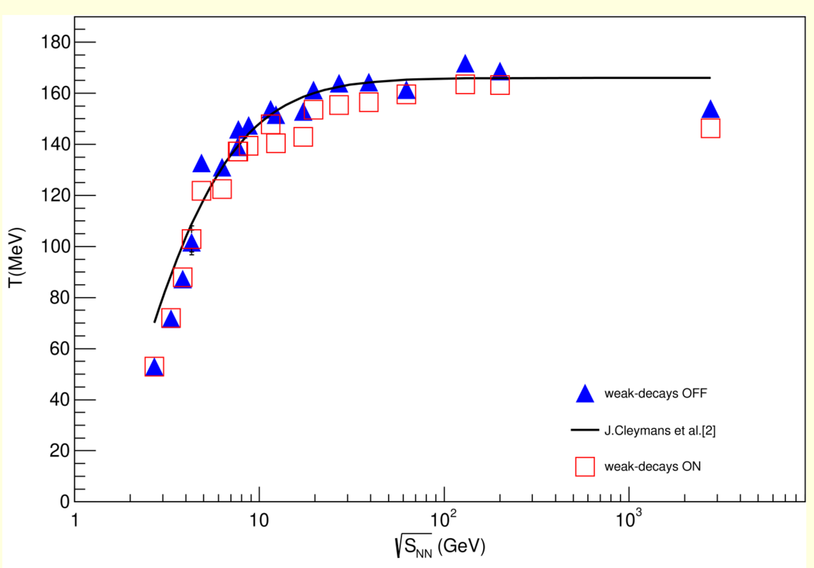
__Note__: For all practical purposes, contribution will be from physical range alone.

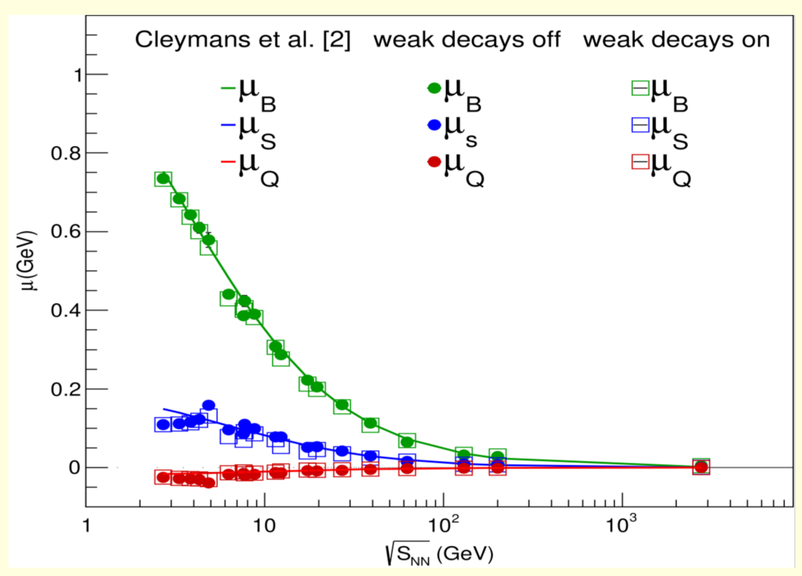
The volume fluctuation is trivially integrated out as:

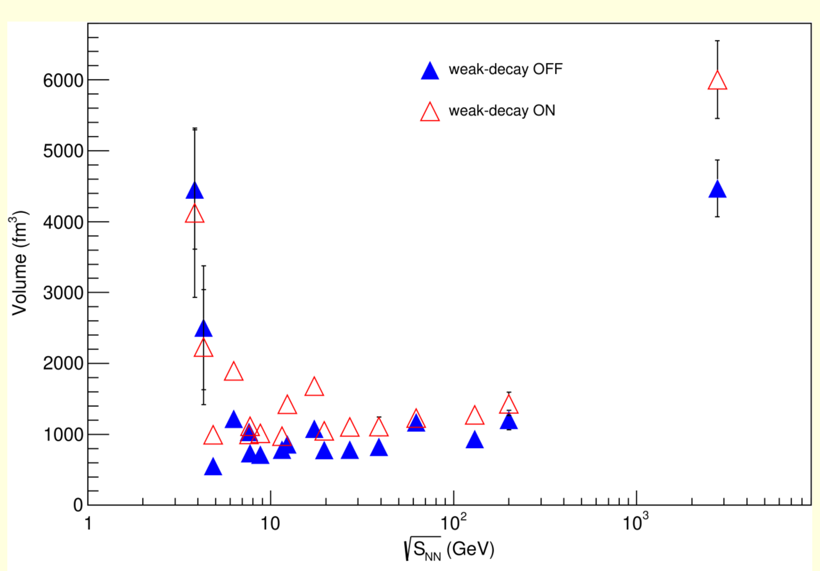
$$V_{eff} = \int e^{-\frac{(V-V_0)^2}{2\sigma_V^2}}\, dV$$

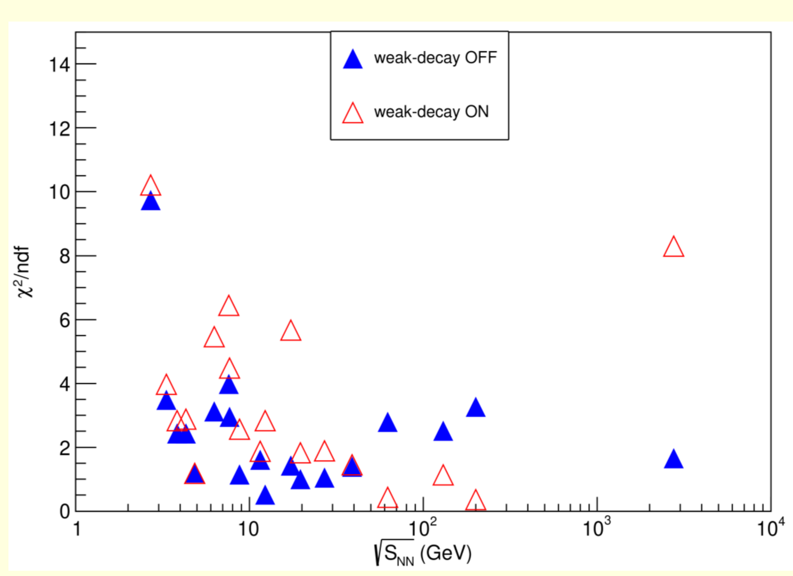
3. Results-I

- The mean thermal parameters extracted from mean hadron yields:



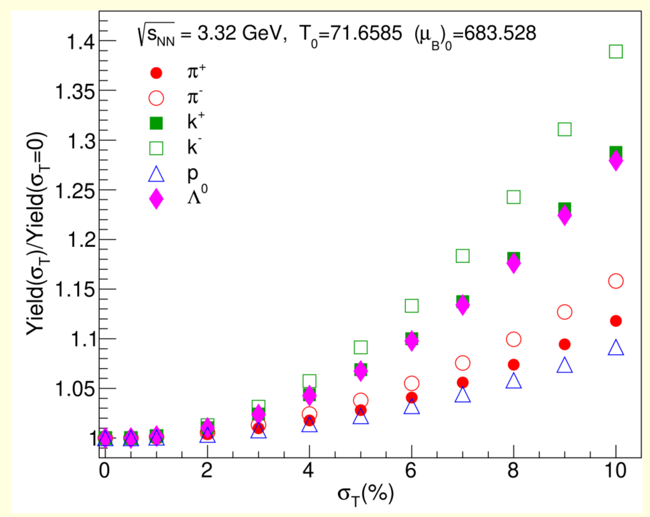


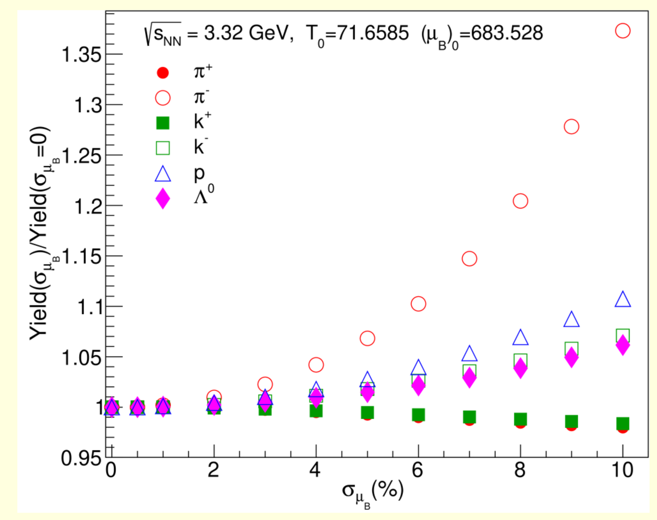


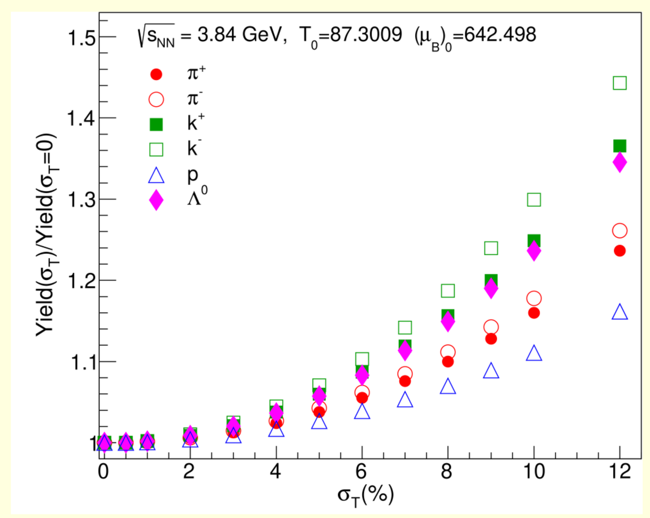


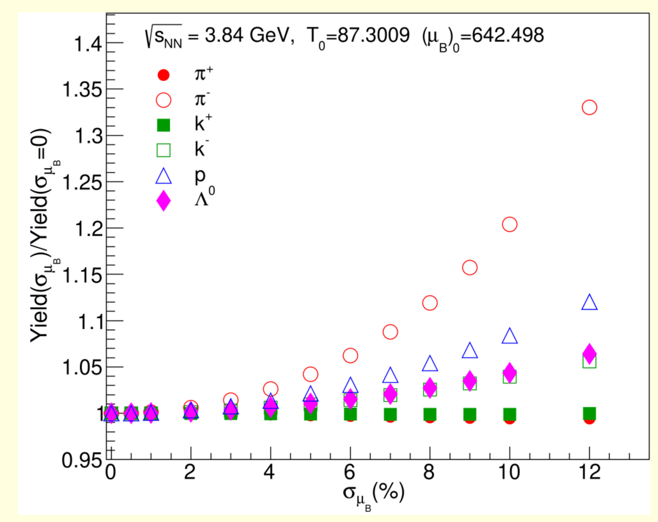
4. Results-II

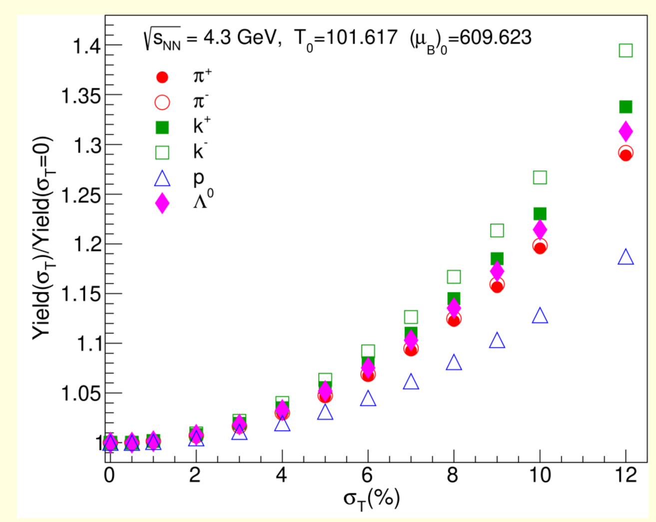
- Effect of fluctuation of thermal parameters on mean hadron yields:

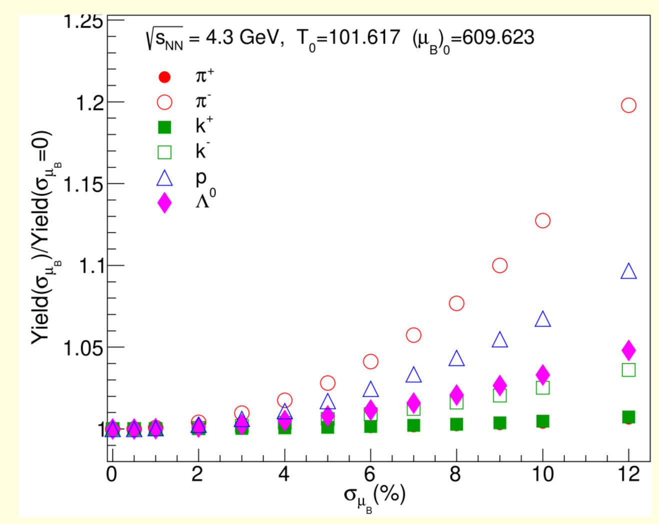


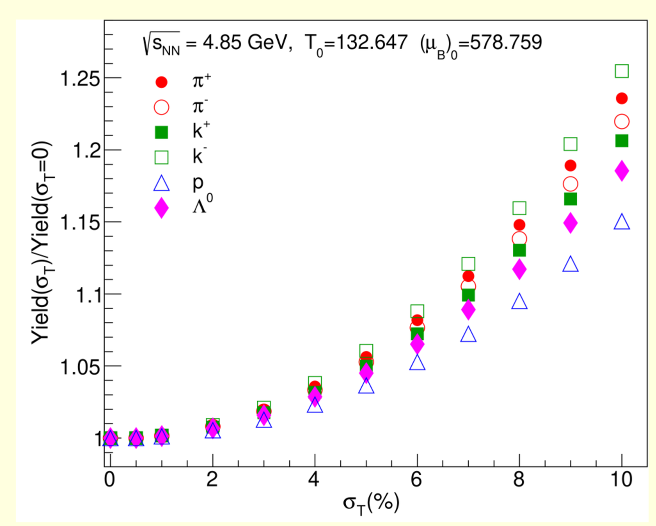


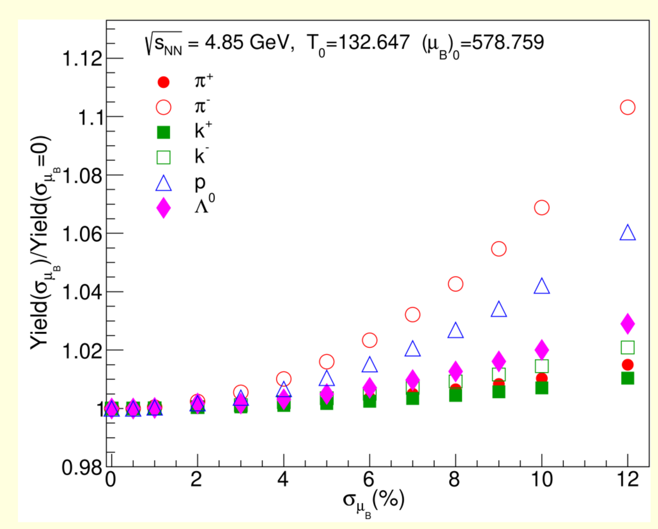


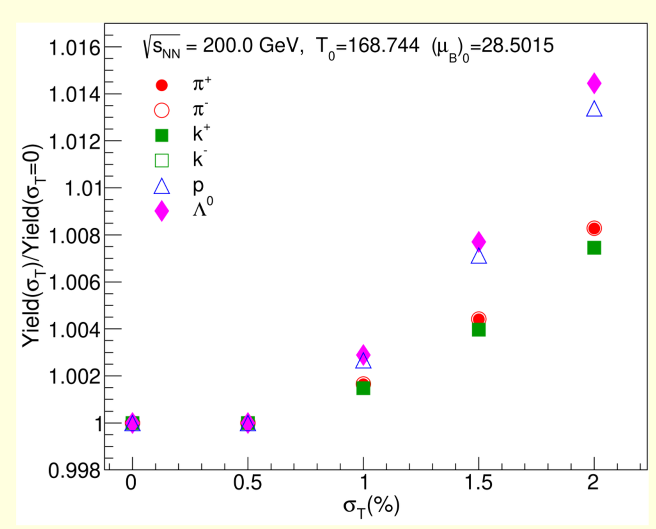


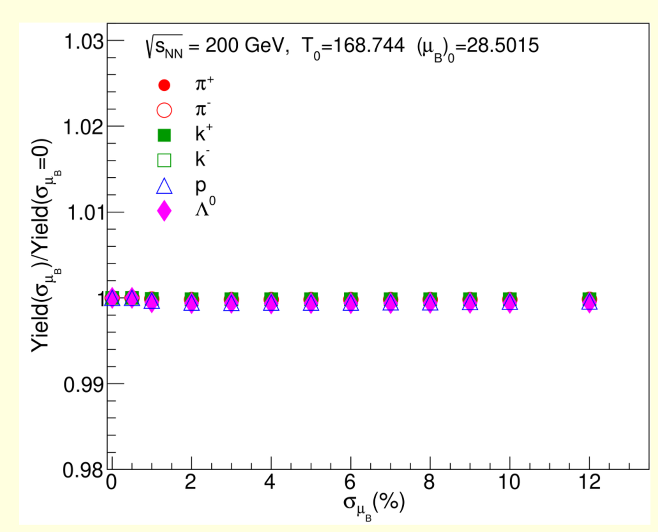












5. Summary

- σ_T and σ_{μ_B} increase the hadron yields at all $\sqrt{S_{NN}}$, except at $\sqrt{S_{NN}}$=200 GeV where the effect of σ_{μ_B} is negligible as we have a mesonic fireball.
- The general rise in the hadron yields with σ_T and σ_{μ_B} could be tamed by a proportionally decreasing volume. This can lead to non- trivial correlations between V and σ_T and σ_{μ_B} . This calls for detailed investigation in the future with best Chi-square estimates for such a enlarged parameter set. Such a scenario will have significant implications in the search for the QCD critical point.

References:

1. V. Skokov, B. Friman, K. Redlich , Phys. Rev. C 88, 034911 (2013).
2. J. Cleymans, H. Oeschler, K. Redlich and S. Wheaton, Phys. Rev. C 73, 034905 (2006).

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