# Fluctuations in Lambda Multiplicity Distribution in Au+Au collisions at $\sqrt{s_{NN}} = 3.0$ GeV at STAR

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**Abstract:** The study of nuclear matter over a wide range of collision energy is provided by the RHIC Beam Energy Scan (BES). One focus of the program, namely to locate the critical point (CP) in the QCD phase diagram, is closely tied to the measurement of kurtosis in net-proton multiplicity distribution as a function of $\sqrt{s_{NN}}$. Previous results from BES-I obtained with $3.1\sigma$ significance motivated us to increase the statistics and to extend the collision energy down to $\sqrt{s_{NN}} = 3.0$ GeV in the BES-II.
The event-by-event fluctuations in net-lambda multiplicity distribution for the first BES showed that the cumulant ratios have a similar energy and multiplicity dependence compared to those for protons, and the observed deviation from Poisson baseline can be attributed to baryon number and strangeness conservations. It is also known from the previous work that the derived freeze-out parameters show sensitivity to the quark content of the hadrons, implying a quark mass dependence in the process of hadronization. We present in this poster, the lambda fluctuation analysis in Au+Au collisions at the lowest collision energy ($\sqrt{s_{NN}} = 3.0$ GeV), where we continue the comparison with proton fluctuations and analyze the behaviour of both baryons, specifically in terms of their difference in quark content and applicable conservation laws.

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# Motivation: Net Lambda Fluctuation Analysis

- Lambda cumulant ratios ($C_2/C_1$ and $C_3/C_2$) show similar $\sqrt{s_{NN}}$ dependence compared with protons.
- Continue with the study of energy dependence of Net-Lambda fluctuations in particular for higher order cumulants and lower $\sqrt{s_{NN}}$.

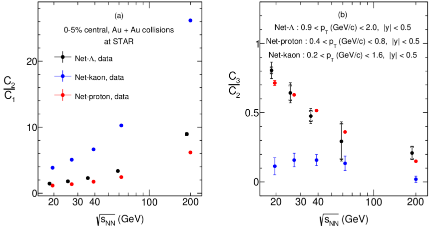


Figure 1: Phys. Rev. C 102, 024903 (2020)

A proxy with both S and B quantum numbers, gives the opportunity to investigate not only **strangeness fluctuations** but also freeze-out parameters in the context of **quark-mass dependence**.

Cumulants of the distribution can be related with theoretical thermodynamic susceptibilities as:

$$\frac{C_2}{C_1} = \frac{\chi^B_{2,\mu}}{\chi^B_{1,\mu}}, \qquad \frac{C_3}{C_2} = \frac{\chi^B_{3,\mu}}{\chi^B_{2,\mu}}, \qquad \frac{C_4}{C_2} = \frac{\chi^B_{4,\mu}}{\chi^B_{2,\mu}}$$

**Chemical freeze-out**:

- Relate fluctuations with freeze-out parameters.
- Study freeze-out parameters in the context of quark-mass dependence.

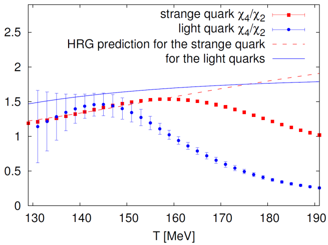


Figure 2: R. Bellwied, et. al. Phys. Rev. Lett, vol. 111, no. 20, p. 202302, 2013.

| | |
|---|---|
| **System and Collision Energy** | Au+Au collisions at $\sqrt{s_{NN}} = 3.0$ GeV, fixed target mode. |
| **Centrality Definition** | Charged particle multiplicity from $\eta$ : $[-2, 0]$ in TPC, excluding protons. |
| **Charged particle selection** | Protons and pions to reconstruct lambda particles. |
| **n$\sigma$ (p and $\pi$)** | $<3$ |
| **NHitsFit** | $>15$ |

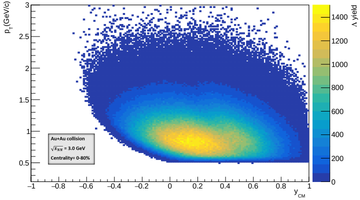


Figure 4: Lambda Acceptance

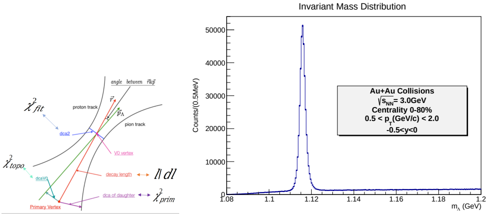


Figure 3: Lambda reconstruction was obtained using KF-Package. High purity and significance achieved in the reconstruction.

## Cumulants corrections

- **Centrality bin width correction:** Cumulants are calculated at each bin multiplicity and then averaged in the centrality definition in order to suppress volume fluctuation.
- **Efficiency correction:** Follow a binomial distribution and track-by-track efficiency correction. T Nonaka et al. In: Phys. Rev. C. 95.064912 (2017) X. Luo and T. Nonaka. In: Phys Rev. C. 99, 044917 (2019)
- **Statistical Errors:** Bootstrap method.
- **Systematic Errors:** Varying track cuts, topological cuts, PID criteria and efficiency.

# Centrality Dependence of Cumulant and Cumulant Ratios

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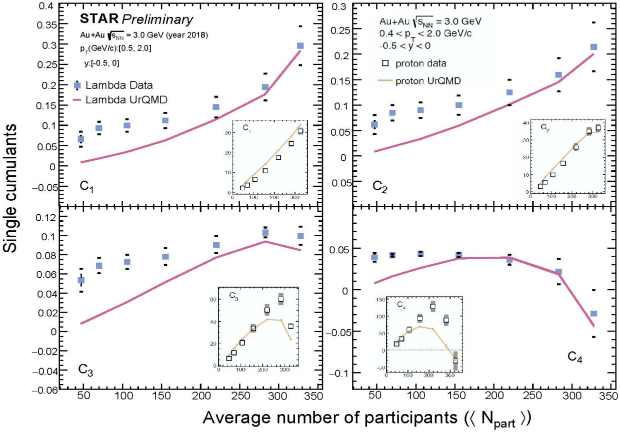
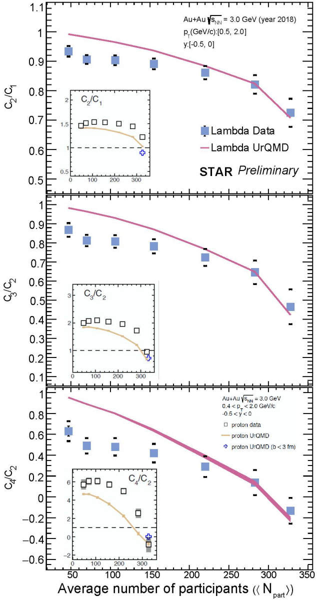
- **Low multiplicity** of lambda particles is obtained at $\sqrt{s_{NN}} = 3.0$ GeV.
- High order cumulants($C_3$ and $C_4$) show **sensitivity to centrality** definition.
- Cumulant ratios follow a **Poisson baseline** for peripheral centrality bins.
- Cumulant ratios suggest **suppression** is caused by baryon and strangeness conservation numbers.
- Transport model **UrQMD** describe the trend of data.
- Lambda cumulant and cumulant ratios **trends show similar behaviour** compared with proton data.

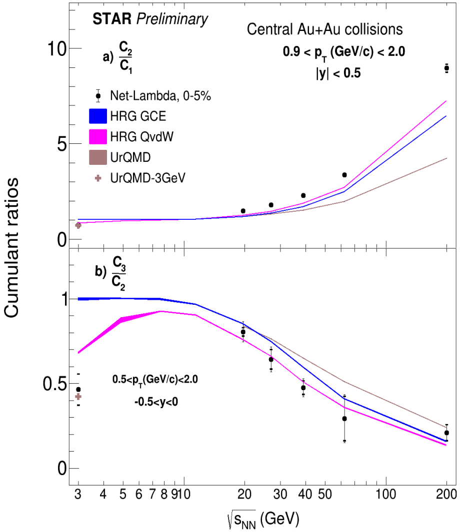



https://drupal.star.bnl.gov/STAR/presentations

# Center of Mass Energy Dependence of Cumulant Ratios

- **Strong suppression** for lambda cumulant ratios is observed for low $\sqrt{s_{NN}}$.
- Quantum Van Der Waals-HRG has **better agreement** with the data than Ideal-HRG at low $\sqrt{s_{NN}}$ (V.Vovchenko et.al. Comput. Phys. Commun. 244, 295,2019).
- **Hadronic interactions** at $\sqrt{s_{NN}} = 3.0$ GeV contribute to the suppression of high order cumulant ratios, shown by the QvdW-HRG model which includes repulsive interactions between baryons (V.Vovchenko et.al. Phys. Rev. C 100, 054904,2019).




## Summary

- Lambda particle show lower multiplicity compared with protons at $\sqrt{s_{NN}} = 3.0$ GeV.
- Both lambda particle and proton $C_4/C_2$ show strong suppression and similar cumulant trends at $\sqrt{s_{NN}} = 3.0$ GeV (See Yu Zhang's presentation).
- Suppression in lambda particles is mainly due to baryon and strangeness conservation effects and hadronic interactions.