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 showing non-monotonic energy dependence with 3.1σ 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 from the BES-I 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 $\sqrt{s_{NN}}$.

$C_1 = \langle N \rangle$

$C_2 = \langle (\delta N)^2 \rangle$

$C_3 = \langle (\delta N)^3 \rangle$

$C_4 = \langle (\delta N)^4 \rangle - 3\langle (\delta N)^2 \rangle^2$

$C_2/C_1 = \sigma^2/M$

$C_3/C_2 = S\sigma$

$C_4/C_2 = \kappa\sigma^2$

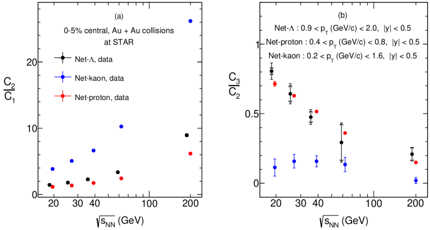


Figure 1: STAR, Phys. Rev. C 102, 024903 (2020)

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 lambda fluctuations with freeze-out parameters, from light charged particles and strange particles.
- Study freeze-out parameters in the context of quark-mass dependence as function of $\sqrt{s_{NN}}$.

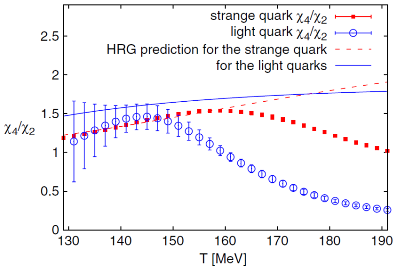


Figure 2: R. Bellwied, et. al. Phys. Rev. Lett, vol. 111, no. 20, p. 202302, 2013.

Analysis Details

System and Collision Energy	Au+Au collisions at $\sqrt{s_{NN}} = 3.0$ GeV, fixed target mode.
Centrality Definition	Charged particle multiplicity from η : $[-2, 0]$ in TPC, excluding protons.
Daughter particles PID information	Proton: $p_T \geq 0.4$ GeV/c Pion: $p_T \geq 0.15$ GeV/c
nσ (p and π)	<3
NHitsFit	>15
Lambda purity	$= 91\%$
Lambda acceptance cuts	y : $[-0.5, 0]$ p_T : $[0.5, 2]$ GeV/c

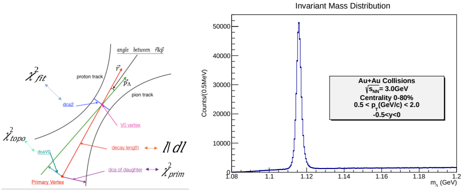


Figure 3: KFParticle-Package, χ^2 criterion diagram (S. Gorbunov, On-line reconstruction algorithms for the CMB and ALICE experiments, 2013)(I. Kisel (CBM), J. Phys. Conf. Ser. 1070, 012015 (2018)).

Lambda reconstruction was obtained using the **KFParticle-Package**.

It is based on the **state vector** of the particles to calculate the decay vertex, momentum and energy of the mother particle. The **quality of the reconstruction** is done using a χ^2 criterion based on the **covariance matrix**.

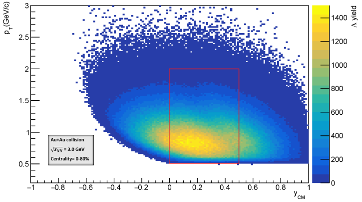


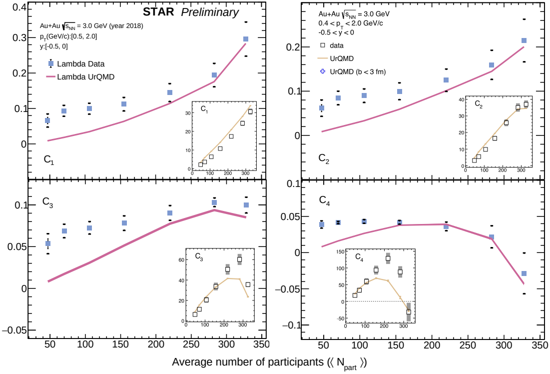
Figure 4: Lambda Acceptance.

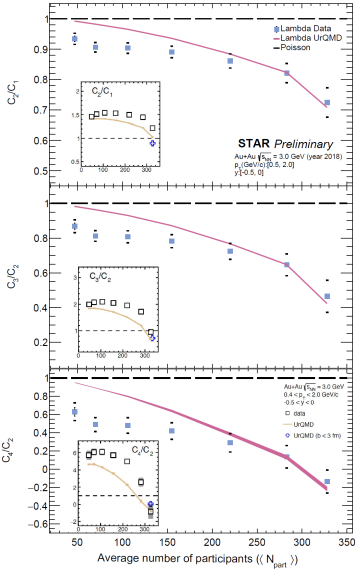
Cumulants corrections

- **Centrality bin width correction:** Cumulants are calculated at each multiplicity bin and then average in the centrality bin in order to suppress volume fluctuation.
- **Efficiency correction:** Follow a binomial distribution and track-by-track efficiency correction. T. Nonaka et al, Phys. Rev. C. 95.064912 (2017) X. Luo and T. Nonaka, 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

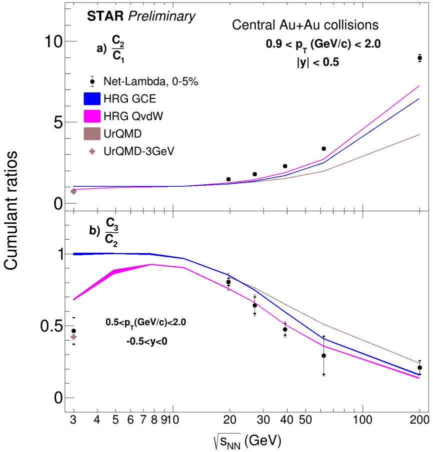
- **Low multiplicity** of lambda particles is obtained at $\sqrt{s_{NN}} = 3.0$ GeV.
- Cumulant ratios in peripheral collisions approach a **Poisson baseline**.
- Cumulant ratios show **suppression** compared to the Poissonian baseline.
- Transport model **UrQMD** describes the trend of data.
- Lambda cumulant and cumulant ratios **show similar trends** compared with proton data.





Strong suppression for lambda cumulant ratios is observed for low $\sqrt{s_{NN}}$, likely due to two sources:

- **Conservation laws (B and S)**, in particular the important contribution of strangeness conservation at low $\sqrt{s_{NN}}$ (Phys. Rev. C 102, 024903 (2020)).
- **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 short range repulsive interactions between baryons (V.Vovchenko et.al. Phys. Rev. C 100, 054904,2019) and describes better the trend of data than the ideal case (V.Vovchenko et.al. Comput. Phys. Commun. 244, 295,2019).



Summary

- Lambda particles show lower multiplicity compared with protons at $\sqrt{s_{NN}} = 3.0$ GeV.
- Both lambda particle and proton C_4/C_2 show values below zero and similar cumulant trends at $\sqrt{s_{NN}} = 3.0$ GeV.
- Suppression of C_3/C_2 in lambda data compared with the ideal HRG-GCE is mainly due to baryon and strangeness conservation effects and hadronic interactions.