Measurement of Higher Moments of Net proton, Net charge and Net kaon Distributions in STAR at RHIC

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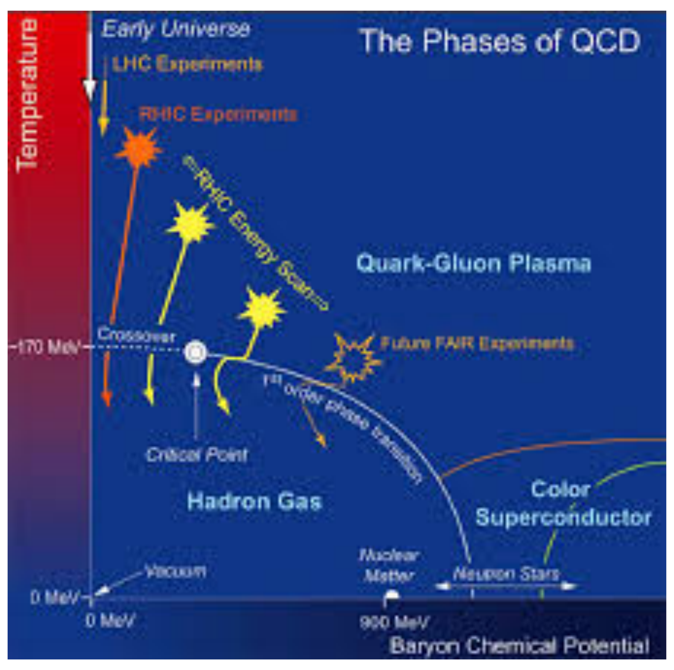
Abstract

Fluctuations in event-by-event distributions of conserved quantities such as net baryon number, net charge, and net strangeness are sensitive to the physics of QCD phase transitions and the QCD critical point. In this poster, we present results on higher moments of multiplicity distributions of net proton (NP), net charge (NC) and net kaon (NK) in Au+Au collisions measured by the STAR experiment in first phase of Beam Energy Scan (BES-I) program at RHIC. In the most central (0-5%) collisions, moments product $\kappa\sigma^2$ of net proton as a function of $\sqrt{s_{NN}}$ exhibit non-monotonic behaviour in the low energy region. The $\kappa\sigma^2$ of net proton shows significant deviation below Poisson baseline (unity) around 19.6 and 27 GeV, large increase above unity at 7.7 GeV. Also deviation from the Hadron Resonance Gas (HRG) model is observed for net proton $\kappa\sigma^2$ at 7.7 and 27 GeV.

Introduction

One of the major goals of the heavy-ion collision experiments is to explore the QCD phase diagram.



- Lattice QCD calculations at finite T and μ_B suggest quark-hadron phase transition to be a crossover. QCD-based calculations find the transition to be first order at large μ_B [1,2].
- The point (T, μ_B) in the QCD phase plane where the first-order phase transition ends is the QCD Critical Point (CP) [3,4].
- Higher-order moments of event-by-event distributions of conserved quantities such as net baryon number (B), net strangeness number (S) and net charge (Q) are predicted to be sensitive to the QCD critical point.
- QCD-based model predicts the sensitivity of higher moments to the QCD critical point in terms of their relations to the correlation length (ξ) [5]. For example: $(\delta N)^2 \sim \xi^2$, $(\delta N)^3 \sim \xi^{4.5}$, $(\delta N)^4 \sim \xi^7$, where $\delta N = N - \langle N \rangle$

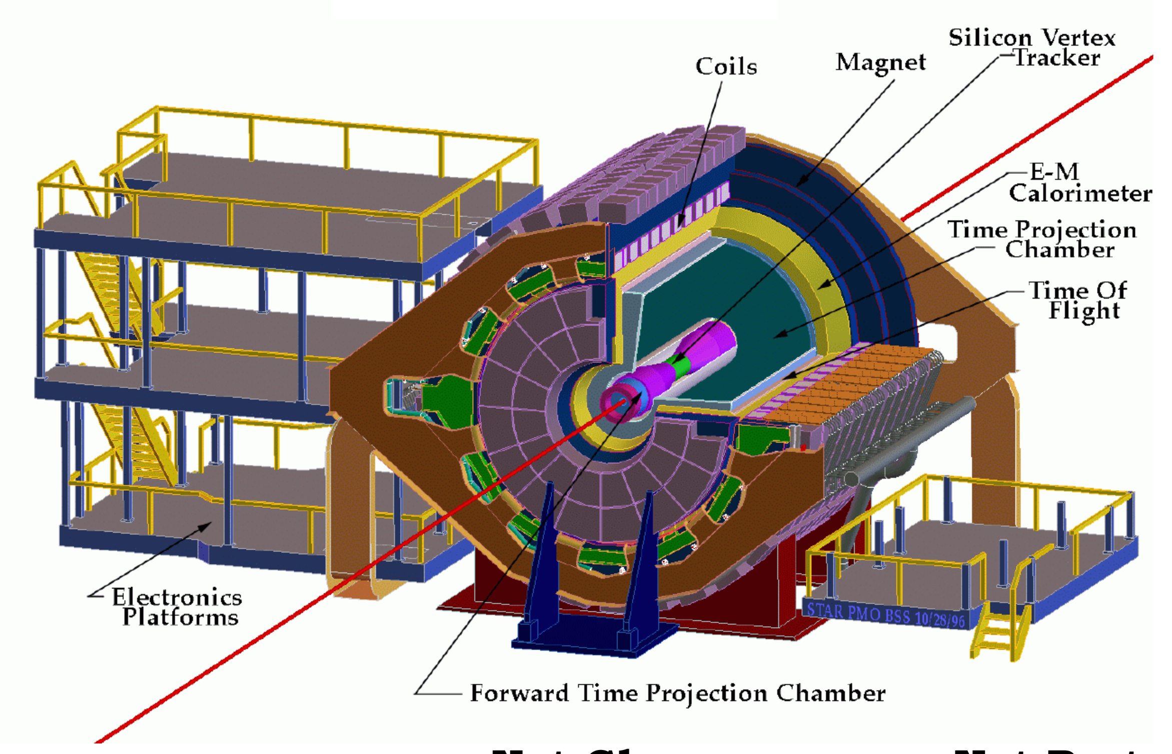
Observables

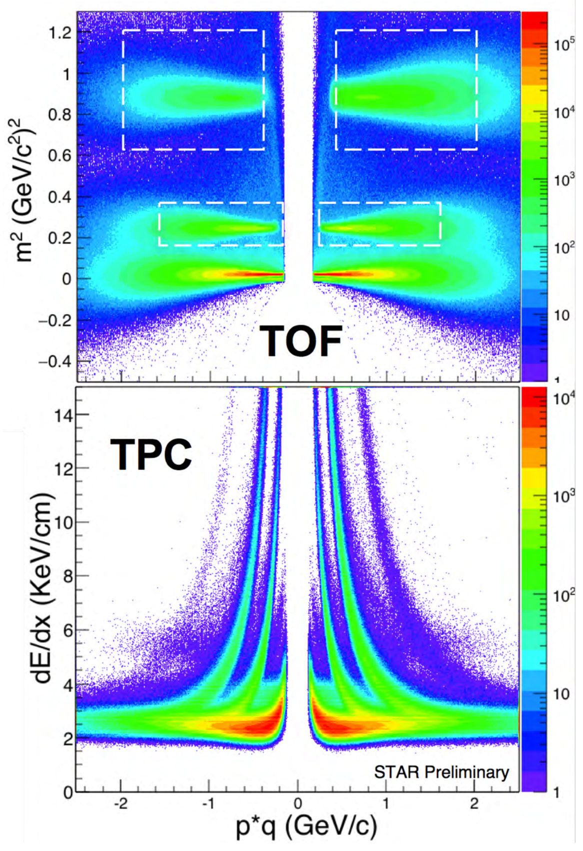
- Cumulants: $C_1 = \langle N \rangle$, $C_2 = \langle (\delta N)^2 \rangle$, $C_3 = \langle (\delta N)^3 \rangle$, $C_4 = \langle (\delta N)^4 \rangle - 3C_2^2$, where $\delta N = N - \langle N \rangle$
- Moments product: $\sigma^2/M = C_2/C_1$, $S\sigma = C_3/C_2$, $\kappa\sigma^2 = C_4/C_2$
- Relations to thermodynamic susceptibility [6-8]:

$$\frac{\sigma^2}{M} = \frac{\chi_q^{(2)}}{\chi_q^{(1)}},\ S\sigma = \frac{\chi_q^{(3)}}{\chi_q^{(2)}},\ \kappa\sigma^2 = \frac{\chi_q^{(4)}}{\chi_q^{(2)}}$$ (q can be B, S, Q)

Experiment

The Solenoidal Tracker At RHIC

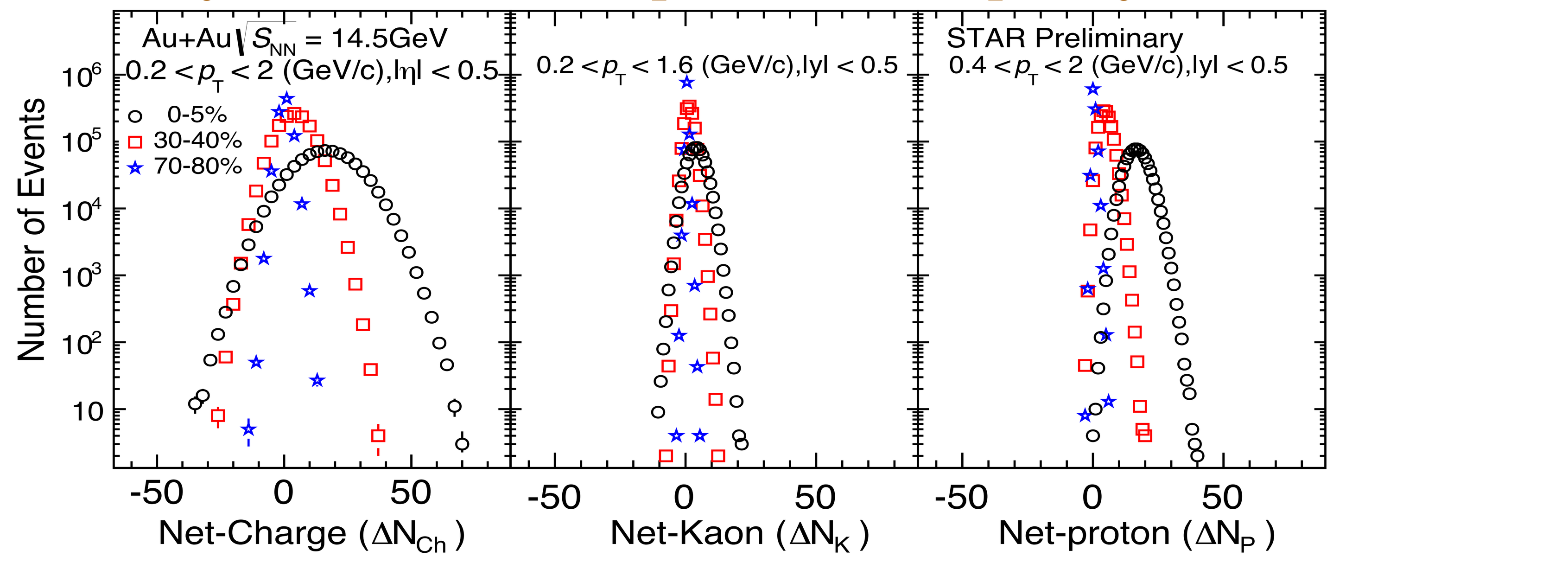




	Net Charge	Net Proton	Net Kaon
Phase space cuts	**0.2 < p_T(GeV/c) < 2.0 $\lvert\eta\rvert$ < 0.5**	**0.4 < p_T(GeV/c) < 2.0 $\lvert y\rvert$ < 0.5**	**0.2 < p_T(GeV/c) < 1.6 $\lvert y\rvert$ < 0.5**
Particle identification	Charged particles. **(TPC)** Spallation protons removed requiring proton $p_T > 0.4$ GeV/c and $\lvert n\sigma_P\rvert < 2.0$	**0.4 < p_T(GeV/c) < 0.8 $\lvert n\sigma_P\rvert$ < 2.0 (TPC)** **0.8 < p_T(GeV/c) < 2.0 $\lvert n\sigma_P\rvert$ < 2.0 and 0.6 < $m^2(GeV^2/c^4)$ < 1.2 (TPC+TOF)**	**0.2 < p_T(GeV/c) < 0.4 $\lvert n\sigma_K\rvert$ < 2.0 (TPC)** **0.4 < p_T(GeV/c) < 1.6 $\lvert n\sigma_K\rvert$ < 2.0 and 0.15 < $m^2(GeV^2/c^4)$ < 0.4 (TPC+TOF)**
Centrality determination (avoid auto-correlations)	Efficiency uncorrected multiplicity of charged tracks from TPC in **0.5 < $\lvert\eta\rvert$ < 1.0**	Efficiency uncorrected multiplicity of charged tracks from TPC in **$\lvert\eta\rvert$ < 1.0** excluding protons and antiprotons.	Efficiency uncorrected multiplicity of charged tracks from TPC in **$\lvert\eta\rvert$ < 1.0** excluding kaons and antikaons.

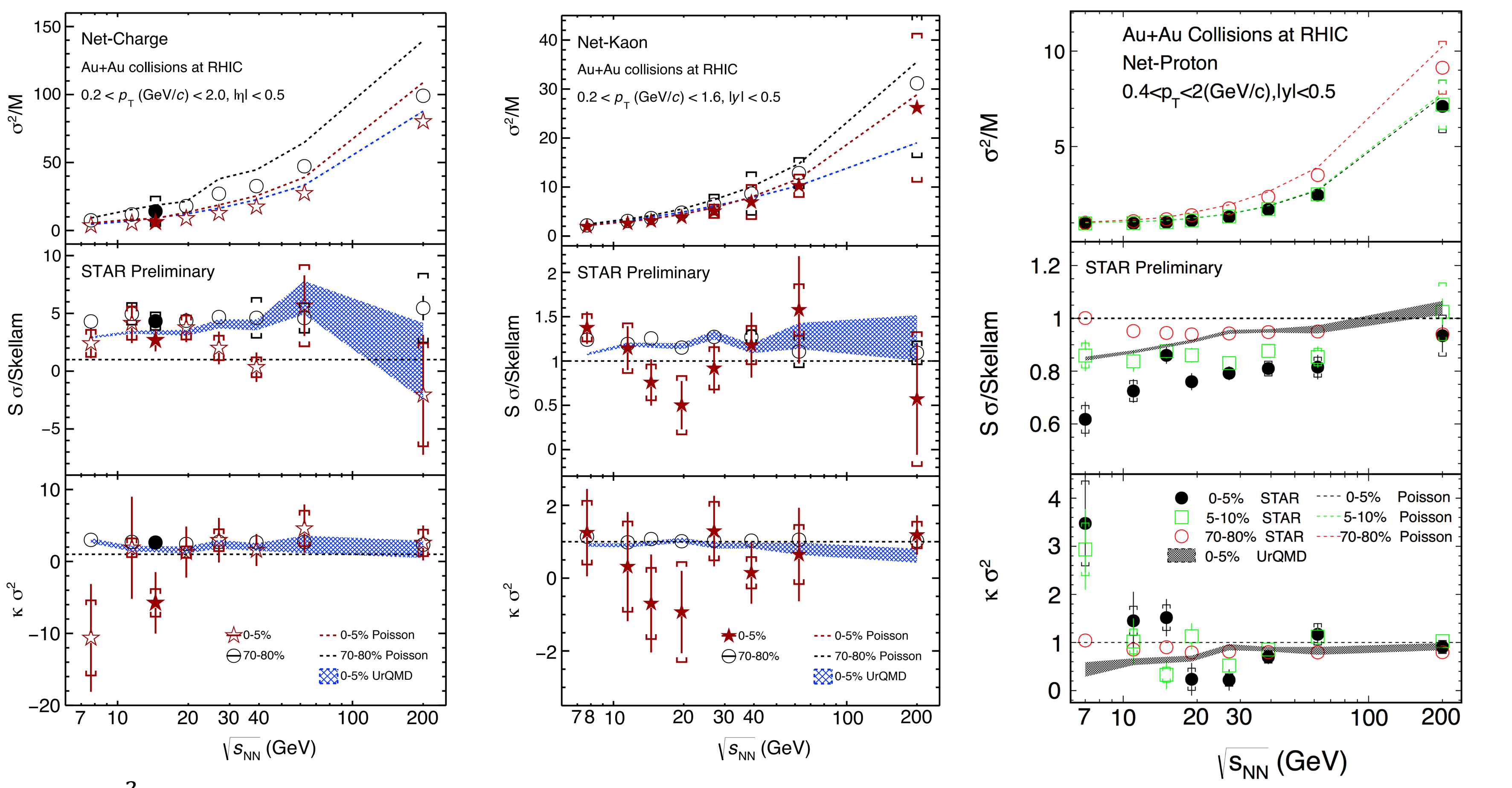
Results

Efficiency-uncorrected net particle multiplicity distributions



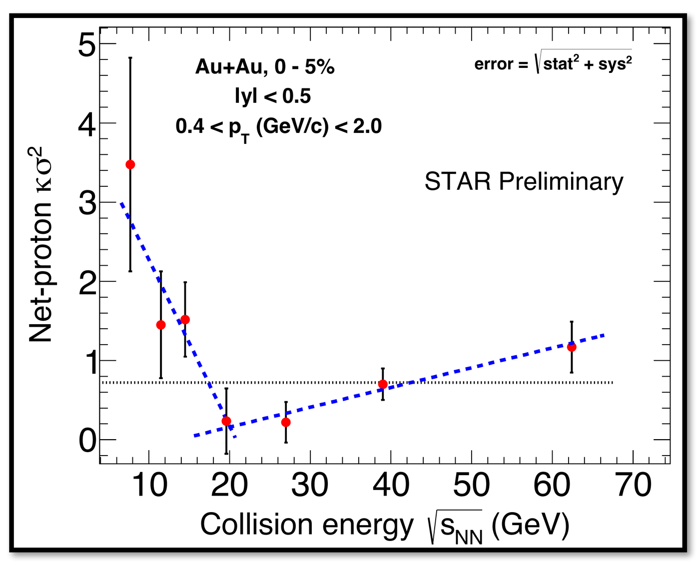
- Mean value of net particle increases from peripheral to central collisions.
- The standard deviation (σ) of multiplicity distribution also increases from peripheral to central collisions.
- Net charge distribution has the largest value of σ in comparison to net kaon and net proton distributions.

Collision energy dependence of products of corrected moments

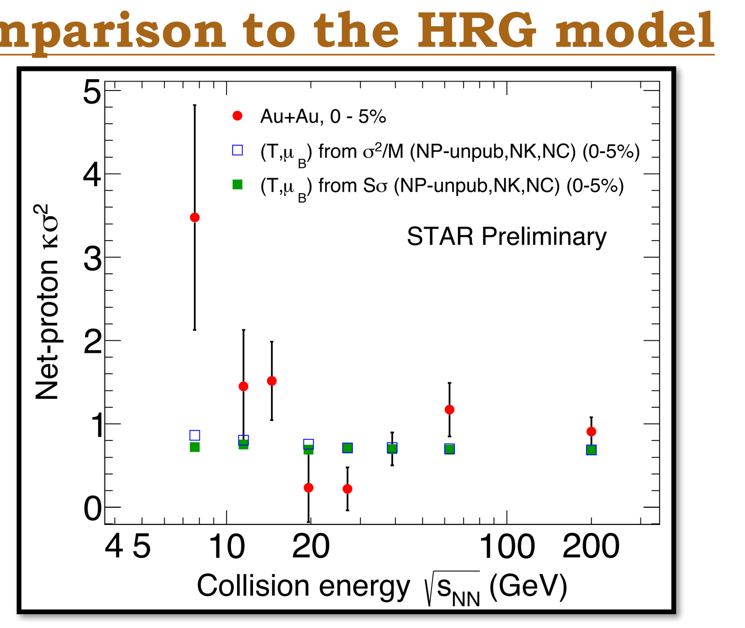


- The $\frac{\sigma^2}{M}$ of net charge, net kaon and net proton monotonically increase with energy.
- Both $S\sigma$/Skellam and $\kappa\sigma^2$ of net charge and net kaon show weak dependence on collision energy, and do not show significant deviation from the UrQMD model calculations [9,10].
- The net proton $\kappa\sigma^2$ for 0-5% central Au+Au collisions is close to unity for $\sqrt{s_{NN}}$ above 39 GeV, show deviations below unity for 19.6 GeV and 27 GeV and enhancement above unity for 7.7 GeV [11,12].

Non-monotonicity of $\kappa\sigma^2$(NP) and comparison to the HRG model



Line	Slope	χ^2/ndf
7.7 – 19.6 GeV	- 0.21 (0.07)	1.01/2
19.6 – 62.4 GeV	+ 0.025 (0.01)	0.37/2
7.7 – 62.4 GeV	0.005 (0.008)	15.4/6



- Deviation at low energies starting from 27 GeV is observed.

- Linear fit of $\kappa\sigma^2$(NP) changes the sign around 19.6 GeV → **Non-monotonic.**
- Slopes for low energy and high energy regions are 3σ away from each other.
- The NP $\kappa\sigma^2$ at low energy deviates from the HRG model predictions →**Non-thermal.**

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Summary/Conclusions

- Higher moments for net charge, net kaon and net proton measured in the STAR experiment are presented.
- In the low energy region, net proton $\kappa\sigma^2$ shows non-monotonic dependence on collision energy. The 3σ difference between slopes for low energy and high energy regions is observed.
- Deviation from the Poisson baseline and UrQMD model is also observed in the low energy region. The HRG model, with the assumption of thermal equilibrium, do not explain the 4th-order moments of net proton.
- The current measurements have large experimental uncertainties. Phase II of the beam energy scan program in STAR at RHIC is envisioned for precise measurement of higher moments during 2019-2021.

The STAR Collaboration
drupal.star.bnl.gov/STAR/presentations