Measurements of off-diagonal cumulants of net-charge, net-proton and net-kaon distributions at STAR

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Abstract

Study of event-by-event fluctuations of conserved charges, i.e. susceptibilities of conserved charges provides a powerful tool to understand and characterize the thermodynamic properties of the hot and dense QCD matter. The ratios of 2nd order off-diagonal to diagonal susceptibilities such as $\chi^{1,1}_{B,S}/\chi^{2}_{S}$, $\chi^{1,1}_{Q,S}/\chi^{2}_{S}$ and $\chi^{1,1}_{Q,B}/\chi^{2}_{B}$, are sensitive to the phase of the matter created in heavy-ion collisions. We report various 2nd order off-diagonal cumulants (i.e. covariances) between net-charge, net-proton and net-kaon along with their ratios to the diagonal cumulants (i.e. variances) as a function of centrality at mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, measured by the STAR experiment at RHIC. These results help to extract the freeze-out parameters by comparing those with theoretical calculations. As the fluctuation measurements depend on the phase space acceptances, we have studied the transverse momentum and pseudorapidity window dependences of the cumulants. The results are reported here.

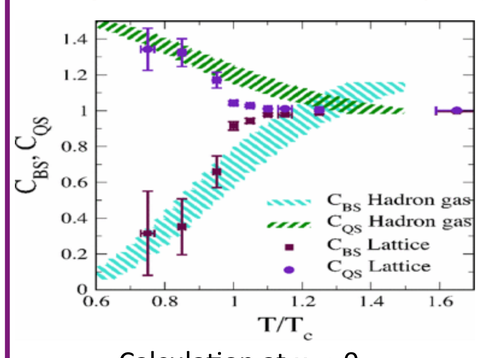
Introduction

- Susceptibilities of conserved quantities, such as, net-Baryon (B), net-Charge (Q), net-Strangeness(S) are sensitive to the onset of QCD phase transition.
- Lattice QCD simulations have shown that **ratios of off-diagonal to diagonal susceptibilities** are sensitive to Phase transition [3,4,8,9,10].

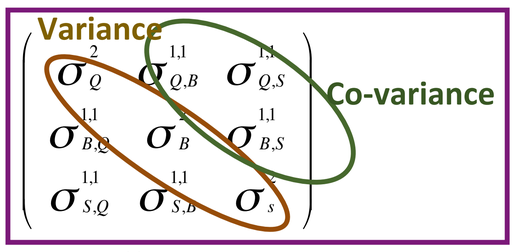
S. Gupta et al., Science, 332, 1525 (2011)
Y. Aoki et al., Nature 443, 675 (2006)

QCD-Phase diagram

A. Majumder et al., PRC 74, 054901 (2006)



Calculation at μ_B =0



$$C_{BS} = -3\frac{\chi^{1,1}_{BS}}{\chi^{2}_{S}} \Rightarrow \begin{array}{l} C_{BS} = 1 \text{ for } T > T_C \\ C_{BS} < 1 \text{ for } T < T_C \end{array}$$

$$C_{QS} = 3\frac{\chi^{1,1}_{QS}}{\chi^{2}_{S}} \Rightarrow \begin{array}{l} C_{QS} = 1 \text{ for } T > T_C \\ C_{QS} > 1 \text{ for } T < T_C \end{array}$$

Ideal Gas: $C_{BS} = C_{QS} = 1$

Recent Lattice, Hadron Resonance Gas (HRG) models have calculated these quantities at finite μ_B . In addition, HRG and UrQMD models use the proxies for B and S.

➢ In Experiments: Proxy used for B and S

Observables: $C_{BS}=-3\sigma^{1,1}_{B,S}/\sigma^{2}_{S}$, $C_{QS}=3\sigma^{1,1}_{Q,S}/\sigma^{2}_{S}$ and $C_{QB}=\sigma^{1,1}_{Q,B}/\sigma^{2}_{B}$

Proxy:

$$Q = Q^{+} - Q^{-}$$
$$B = p - \bar{p}$$
$$S = k^{+} - k^{-}$$

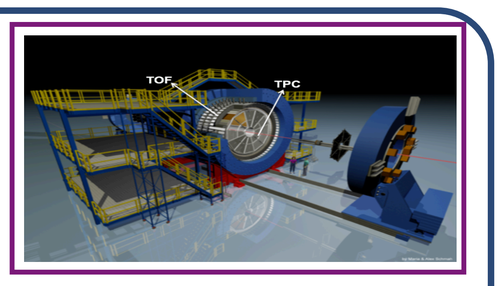
The Goals of the present study are:

- Calculate these observable in the STAR experiment
- Compare results with HRG, UrQMD baseline and Lattice
- Study the dependence on phase space window (η and p_T)

Analysis techniques

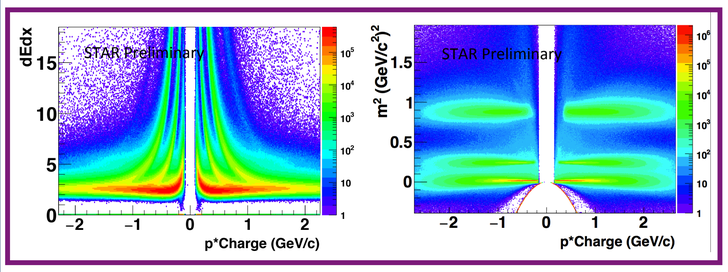
The STAR detector offers

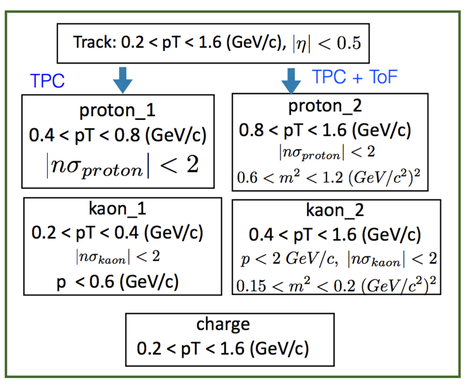
- Uniform p_T and rapidity acceptance
- Full 2π coverage
- Very good particle identification capabilities (TOF and TPC)



We have analyzed the experimental data for **Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV,** a function of centrality, p_T and η windows.

- **Particle Identification** **(|η| < 0.5)**

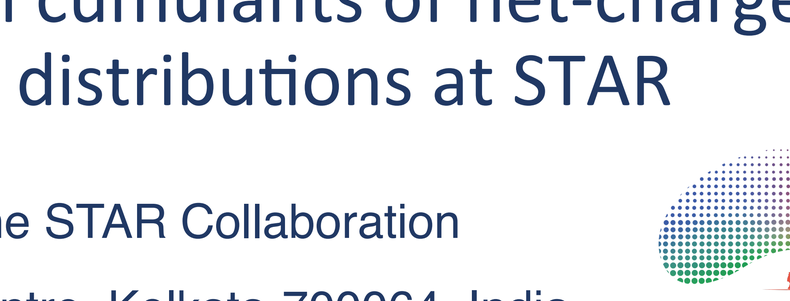




- **Centrality determination**
  Use charged particles (within **0.5 < |η| < 1.0**) excluding the analysis region in order to avoid auto correlation.
- **Centrality bin width correction**: to suppress the volume fluctuation.
- **Statistical errors** : Using analytical methods of error propagation [6][7].
- **Efficiency correction** : Using binomial response functions with separate efficiencies for positive and negative charged particles, k^+, k^-, proton and anti-proton.

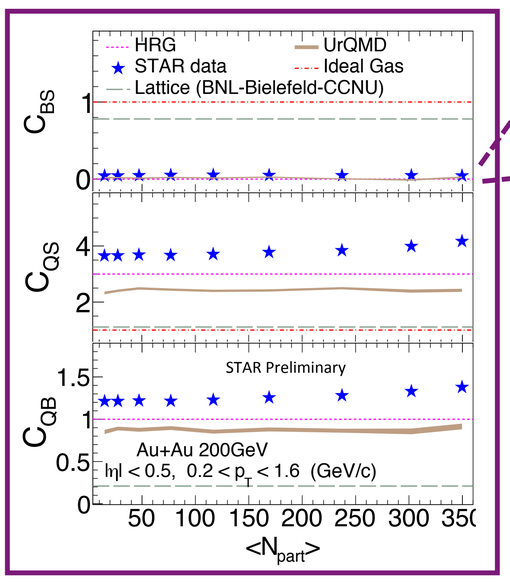
Results

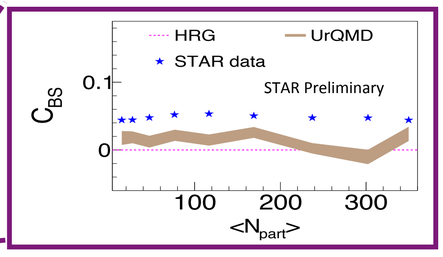
Cumulants (Variances and Co-variances)



- Variances increase with centrality
- σ_{QS} and σ_{QB} are positive but σ_{BS} is negative

Cumulant ratios (C_{XY} ~ α σ^{11}/σ^2)





Comparison of experimental data to Models:

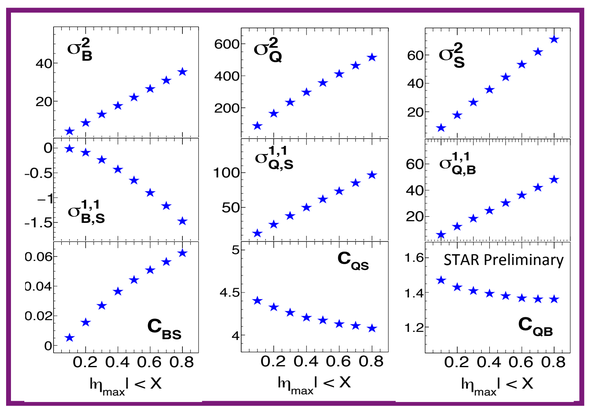
General Trend:

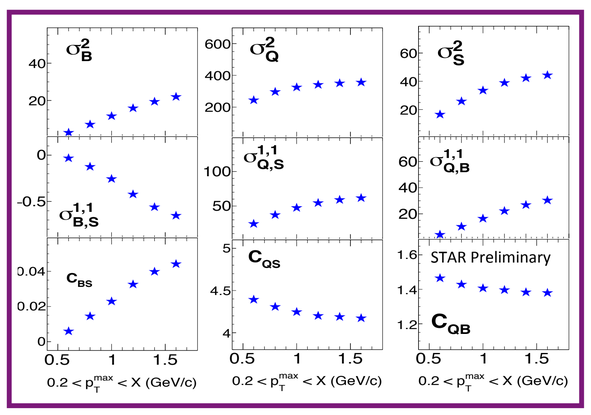
- Data (using proxy for B and S with net-kaon and net-proton) show deviations from Lattice results (T = 156 MeV and μ_B = 0 **including all hadrons**) and ideal gas limits.
- HRG and UrQMD are with same hadron content (pion, kaon, proton) and kinematics as experiment under predict data.
- Data show mild variation with centrality.

➢ C_{BS} : Small but significant deviation from HRG towards lattice prediction
➢ C_{QS} & C_{QB} : Higher compared to HRG and UrQMD.

Cumulants in a finite phase space acceptance

η window dependence **p_T window dependence**





- Variances and co-variances show strong dependence on η and p_T acceptance window
- C_{QS} and C_{QB} show decreasing trend with η and p_T acceptance window.

Summary

- The first measurement of off-diagonal cumulants of conserved charges are presented for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV using pion, kaon and protons.
- Off-diagonal cumulants show strong centrality, p_T and η dependence.
- Data show non-zero C_{BS} although no strange-baryon is present in the data sample.
- Direct comparison to lattice QCD (T_c,μ_B=0) is not possible by using proxies . Results of HRG and UrQMD deviate from STAR data.

Outlook:

- Beam Energy dependence of the ratio of off-diagonal to diagonal cumulants will be presented in near future.

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