Higher Moments of Event-by-Event Net-proton Multiplicity Distributions at RHIC

Xiaofeng Luo *(USTC/LBNL), (for the STAR Collaboration)*

Abstract: Higher moments (Variance (σ^2), Skewness (S), Kurtosis (κ)) of distributions for conserved quantities, such as net-baryon, net-charge and net-strangeness, can be directly related to the thermodynamic susceptibilities in Lattice QCD and Hadron Resonance Gas (HRG) model. Thus, it opens a new domain and also provides us an effective method for probing the bulk properties of nuclear matter and test the QCD theory in the non-perturbative region. The higher moments of net-proton distributions measured in heavy ion collisions have been applied to address three important physics topics. First, it is employed to search for the QCD critical point due to its high sensitivity to the correlation length. The second, it is used to address the thermalization issue in heavy ion collisions. Third, the higher moments of net-proton distributions have been used to constrain the phase transition temperature T_c at zero baryon chemical potential.

1. Definition of Higher Moments:

(1): Variance (σ^2): $\sigma^2 = <(N-<N>)^2>$

(2): Skewness (S): $S = <(N-<N>)^3>/ \sigma^3$

(3): Kurtosis (κ): $\kappa = <(N-<N>)^4>/ \sigma^4-3$

N: Particle multiplicity in single event.

<N>: Mean value of particle multiplicities.

2. Higher Moments and Susceptibilities:

(1) : $\sigma^2 = VT^3 \chi_Q^{(2)}$ (2) : $S = VT^3 \chi_Q^{(3)}$

(3) : $\kappa = VT^3 \chi_Q^{(4)}$ (4): $\kappa \sigma^2 = \chi_Q^{(4)} / \chi_Q^{(2)}$

(5): $S\sigma = \chi_Q^{(3)} / \chi_Q^{(2)}$ (6): $\kappa \sigma /S = \chi_Q^{(4)} / \chi_Q^{(3)}$

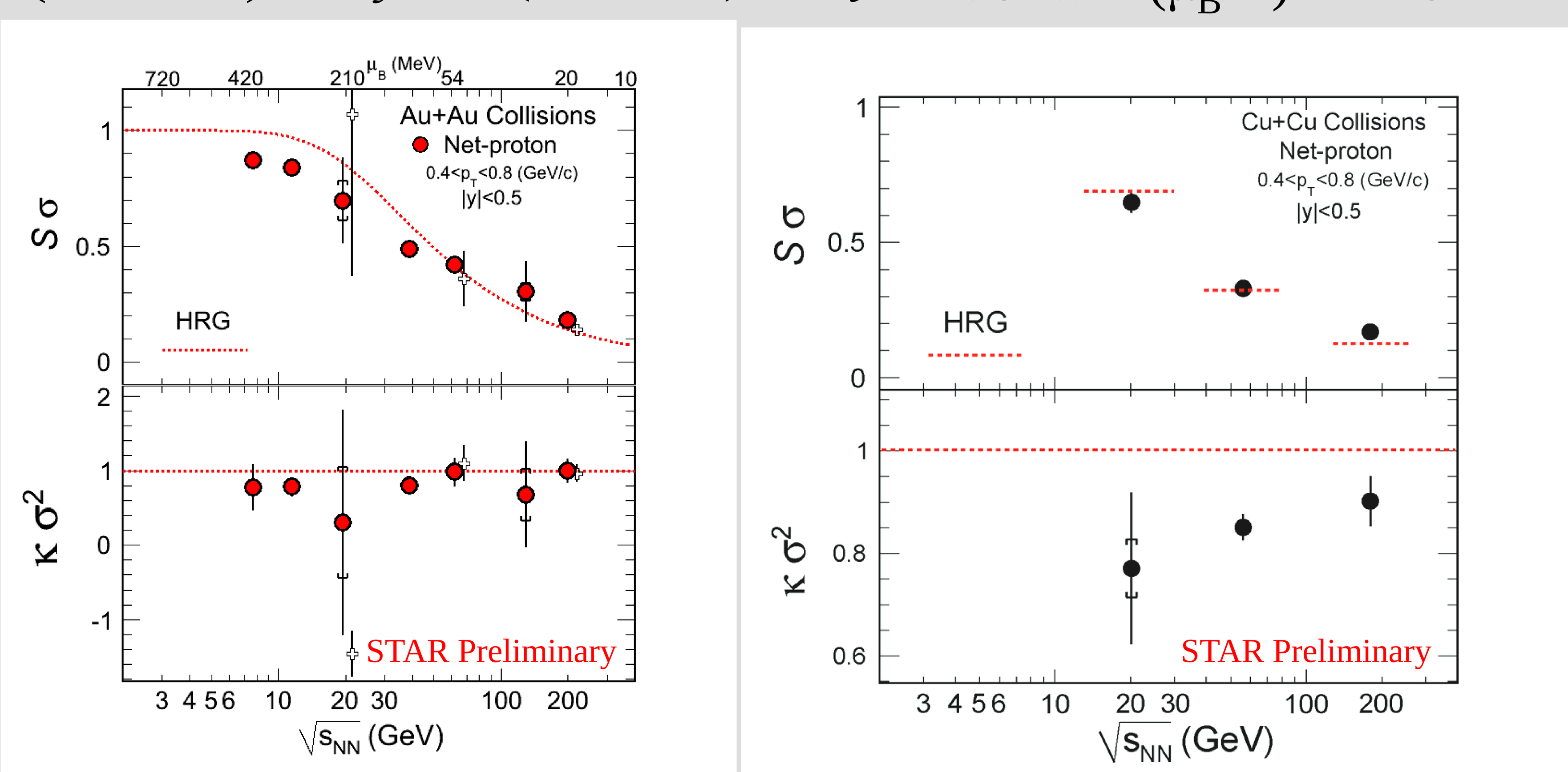
Q=baryon (B), charge (C), strangeness (S).

V, T: Volume and Temperature of system.

3. Search for QCD Critical Point.

(1): Sensitive to Correlation Length (ξ): (2): HRG Model Predictions

$<(N-<N>)^3> \propto \xi^{4.5}$ $<(N-<N>)^4> \propto \xi^7$ $S\sigma=\tanh(\mu_B/T)$ $\kappa \sigma^2=1$



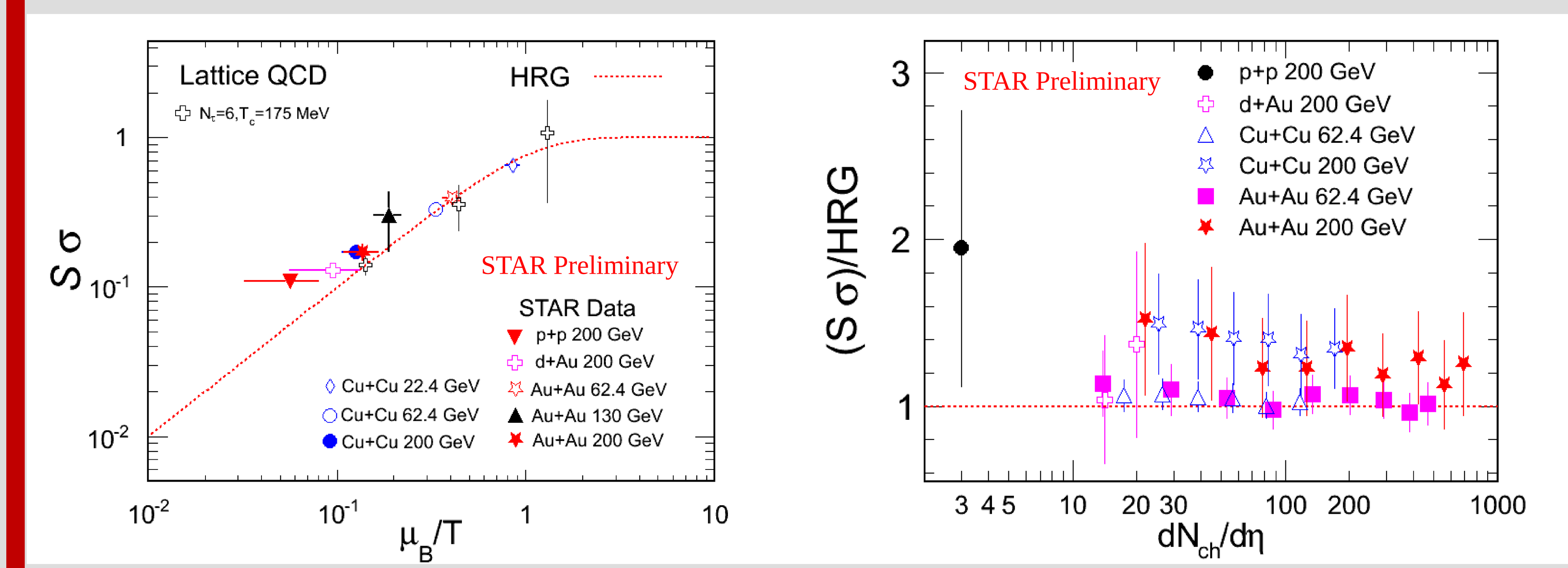
For high energy (62.4, 130, 200 GeV) Au+Au central collisions, the $S\sigma$ and $\kappa \sigma^2$ of net-proton distributions are consistent with Lattice QCD and HRG model, while the results are smaller than the HRG mode calculations below 39 GeV. Please also see the posters (93, 146 , 191) for higher moments studies from STAR Collaboration.

M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).
M. M. Aggarwal et al., Phys. Rev. Lett. 105, 22302 (2010).

4. Address Thermalization Issue.

(1): First time, higher moments of net-proton distributions is applied to address the thermalization issue in heavy ion collisions.

(2): Fluctuations and yields are two basic properties for a thermodynamic system.



The mutual agreements between the μ_B/T extracted from thermal model fits of particle ratio and from the event-by-event fluctuation observable (the $S\sigma$ of net-proton distributions) supports the thermalization of matter created in the heavy ion collisions.

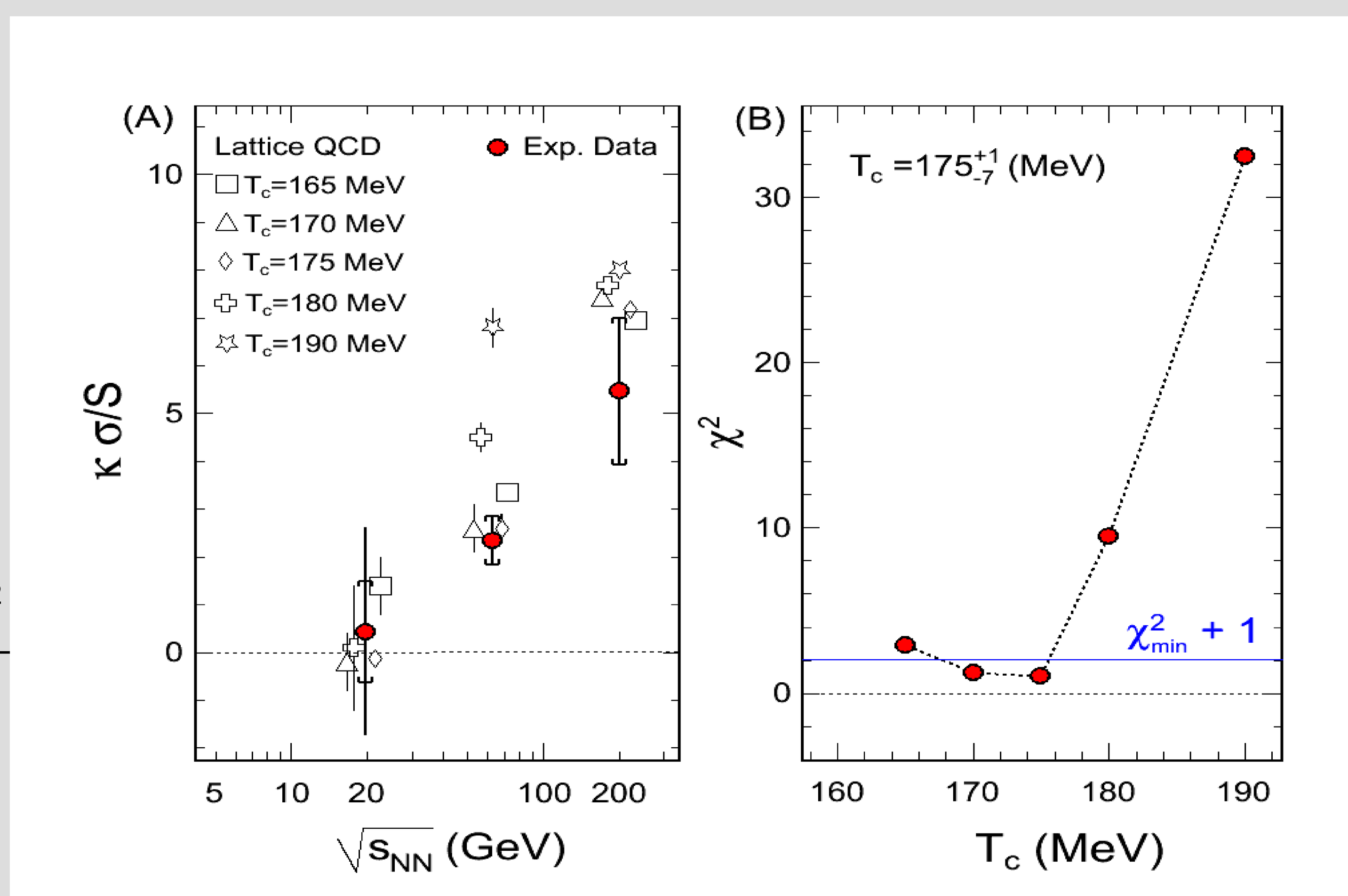
R. V. Gavai and S. Gupta, Phys. Lett. B 696, 459 (2011).
M. M. Aggarwal et al. Phys. Rev. C 83, 34910 (2010).
F. Karsch and K. Redlich, Phys. Lett. B 695, 136 (2011).

5. Determining the Scale of QCD Phase Diagram with STAR Data.

Science AAAS

$m_3=\kappa \sigma /S= \chi_B^{(4)} / \chi_B^{(3)}$

$$\chi^2(T_c)=\sum_{\sqrt{s_{NN}}} \frac{[m_3^{exp}(\sqrt{s_{NN}})-m_3^{Lattice}(\sqrt{s_{NN}},T_c)]^2}{\sigma_{exp}^2+\sigma_{Lattice}^2}$$



Recently, STAR data on higher moments of net-proton multiplicity distributions was used to, for the first time, constrain the phase transition temperature T_c at zero baryon chemical potential by comparing experimental measurements of higher moment with the results from Lattice QCD. This temperature sets a scale of QCD phase diagram. We conclue that the phase transition tempeartue T_c at μ_B=0 is 175 (+1) (-7) MeV.

Paper Accepted by Science

arXiv: 1105.3934