Moments of net-charge multiplicity distribution in Au+Au collisions measured by the PHENIX experiment at RHIC

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Outline

- Introduction
- PHENIX Experiment
- Results
- Comparison to Models
- Conclusion

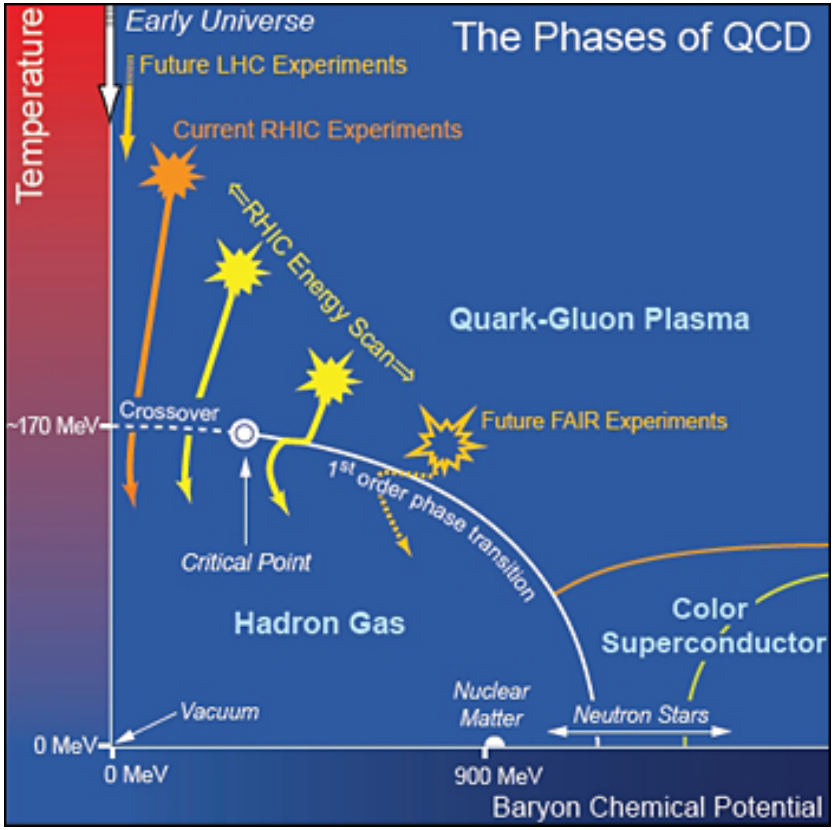
Introduction

- The temperature driven transition at zero μ_B indicate a rapid crossover from the hadronic phase to the QGP phase for realistic u, d and s quark masses.

- The μ_B driven transition at finite T is a first order phase transition.

- Since the first order line originating at zero T cannot end at the vertical axis $\mu_B = 0$, the line must end somewhere in the midst of the phase diagram.

This end point of a first order phase transition line is a critical point (CP) of the second order.



Theory to Experimental observable

Fluctuations of conserved quantities related to thermodynamic susceptibilities

- ***Lattice QCD and Hadron Resonance Gas (HRG) model***

$$\chi_Q^{(1)} = \frac{\langle N_Q \rangle}{VT^3}$$

$$\chi_Q^{(2)} = \frac{\langle (\delta N_Q)^2 \rangle}{VT^3}$$

$$\chi_Q^{(3)} = \frac{\langle (\delta N_Q)^3 \rangle}{VT^3}$$

$$\chi_Q^{(4)} = \frac{\langle (\delta N_Q)^4 \rangle - 3\langle (\delta N_Q)^2 \rangle^2}{VT^3}$$

$$S_Q = \frac{\langle (\delta N_Q)^3 \rangle}{\sigma_Q^3}$$

$$\kappa_Q = \frac{\langle (\delta N_Q)^4 \rangle}{\sigma_Q^4} - 3$$

$$\frac{\sigma_Q^2}{M_Q} = \frac{\chi_Q^{(2)}}{\chi_Q^{(1)}}, S_Q\sigma_Q = \frac{\chi_Q^{(3)}}{\chi_Q^{(2)}}, \kappa_Q\sigma_Q^2 = \frac{\chi_Q^{(4)}}{\chi_Q^{(2)}}$$

→ **Independent of Volume**

(M.Cheng et al, Phys. Rev. D 79, 074505 (2009)
F. Karsch and K. Redlich, Phys. Lett. B 695, 136 (2011))

Connection: Theory to Experimental observable

- HI collisions that pass close to a QCD critical point might demonstrate observable with large fluctuations in correlation lengths (x) of particular global variables.

- The correlation length is related to the various moments of conserved quantities*: net-baryon, net-charge, net-strangeness*

  - Variance : $\sigma^2 = \langle(\Delta N)^2\rangle \sim \xi^2$ where, $\Delta N = N - \langle N\rangle$
  - Skewness: $S = \langle(\Delta N)^3\rangle/\sigma^3 \sim \xi^{4.5}$
  - Kurtosis: $\kappa = \langle(\Delta N)^4\rangle/\sigma^4 - 3 \sim \xi^7$

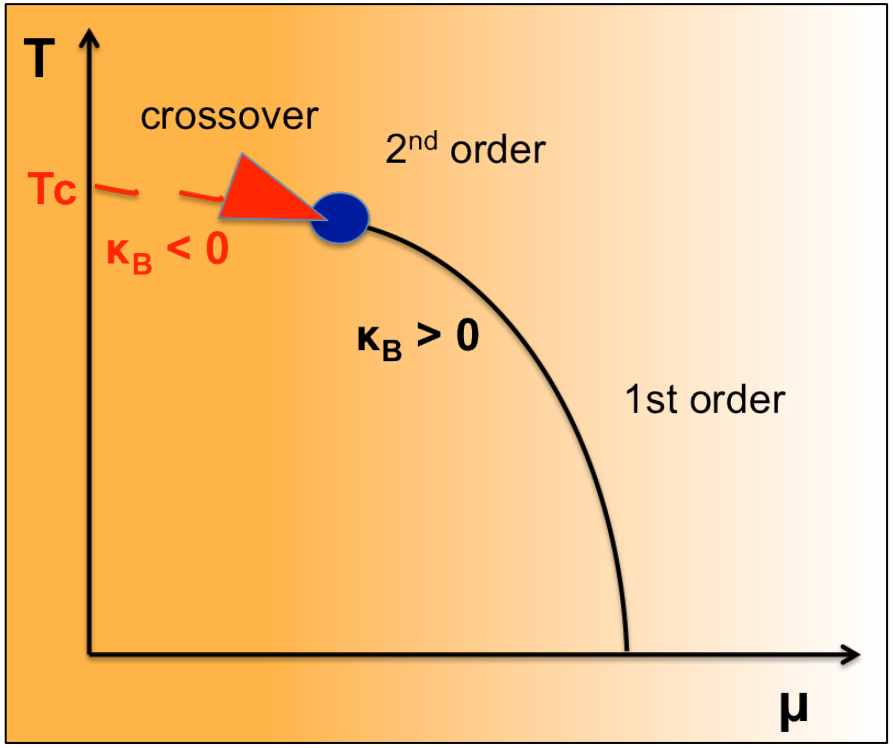
Higher moments are sensitive to non-Gaussian nature
→ amplify the signal.

Since the correlation length is expected to diverge at the CP, it is expected that $S\sigma$ and $\kappa\sigma^2$ will have large values.

*Stephanov et al. (Phys. Rev. D **82** 074008)*
Stephanov, Phys. Rev. Lett. 102, 032301 (2009)

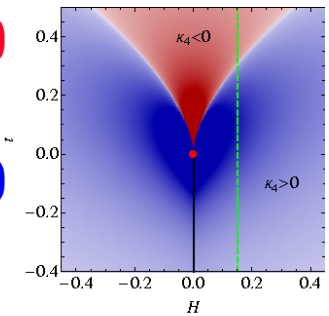
4th Order Cumulant (kurtosis) and the critical point

In the vicinity of the critical point the kurtosis will be negative in a certain T-μ_B region



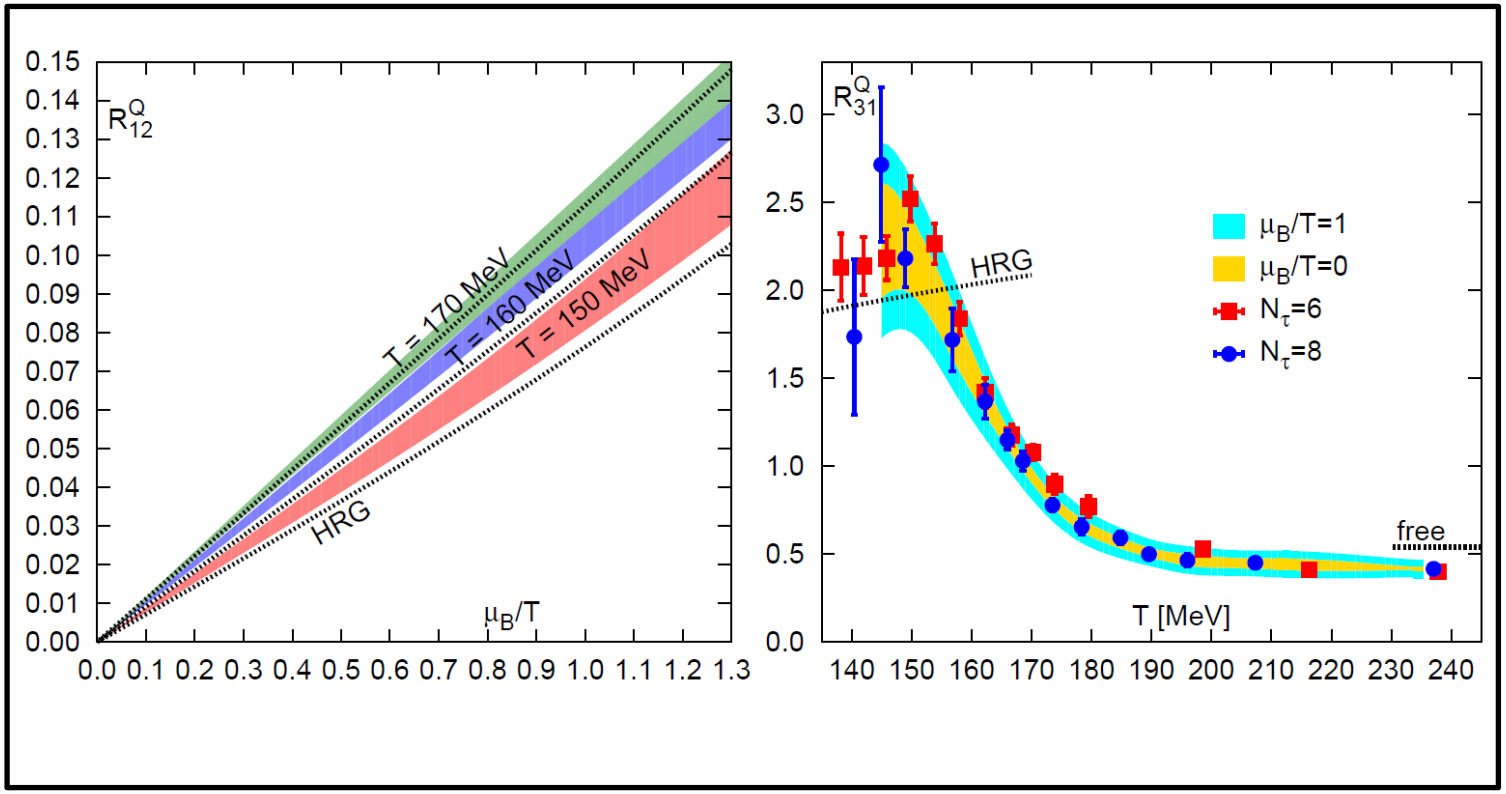
$\kappa_B < 0$

$\kappa_B > 0$



M. Stephanov, PRL 107,052301(2011)

Determination of freeze-out parameters

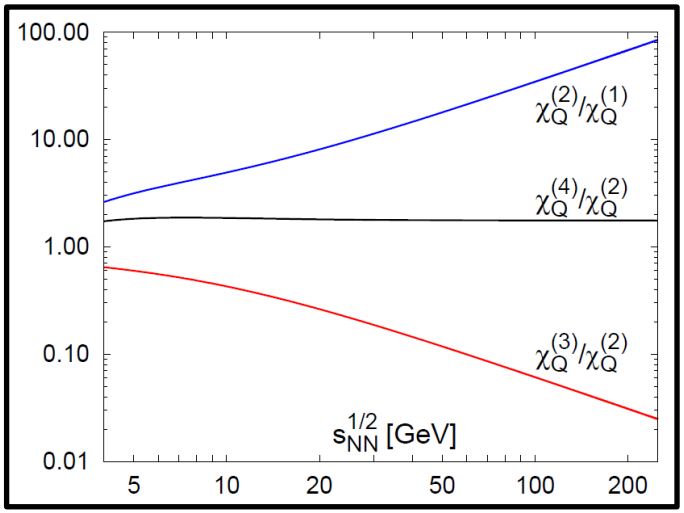


Experimentally measured higher moments can be used to extract the freeze-out parameters

Bielefeld-BNL, Phys. Rev. Lett. 109, 192302 (2012)

How to probe

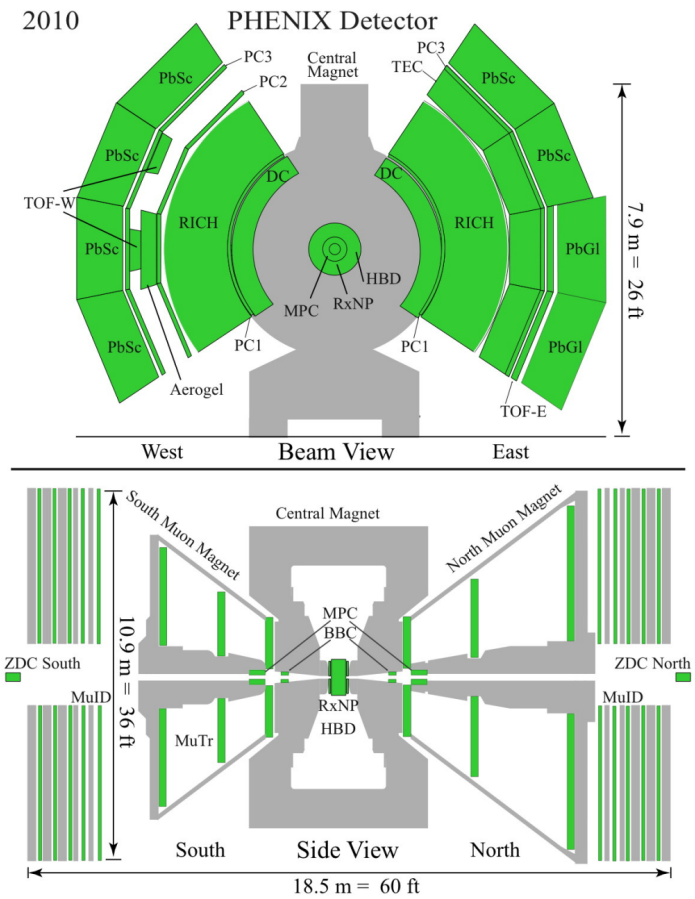
- Any non-monotonic variations of higher moments of conserved quantity Distributions as a function of energy will lead to some critical phenomenon



Baseline from HRG predictions

Phys. Lett. B695 (2011) 136

PHENIX detector at RHIC



Global Detectors:

- BBC (3.0 < |η| < 3.9)
- ZDC (|η| > 6)
- RXNP (1.0<|η|<1.5 [inner]
  (1.5<|η|<2.8 [outer])

Central Arm Detectors :

- DC, PC1, PC2, PC3
- RICH
- ToF
- EmCal

Hadrons, Photons, Electrons

- |η| < 0.35
- Pt > 0.2 GeV/c
- Δϕ = π (2 Arms x π/2)

Forward rapidity arms:
Muons

- $1.2<|\eta|<2.2$
- $p\mu > 1$ GeV/c
- $\Delta\varphi = 2\pi$

Analysis details

- **Au+Au (2010) Data:**
  - **7 GeV ~ 1×10^6**
  - **39 GeV ~ 155×10^6**
  - **62 GeV ~ 476×10^6**
- **Au+Au (2007)Data:**
  - **200 GeV ~ 3.26×10^9**

Centrality selection:

To avoid auto correlation

- **39, 62.4 and 200 GeV using BBC ($3.0 < |\eta| < 3.9$)**
- **7.7 GeV using RxNP ($1.0 < |\eta| < 1.5$ [inner])**

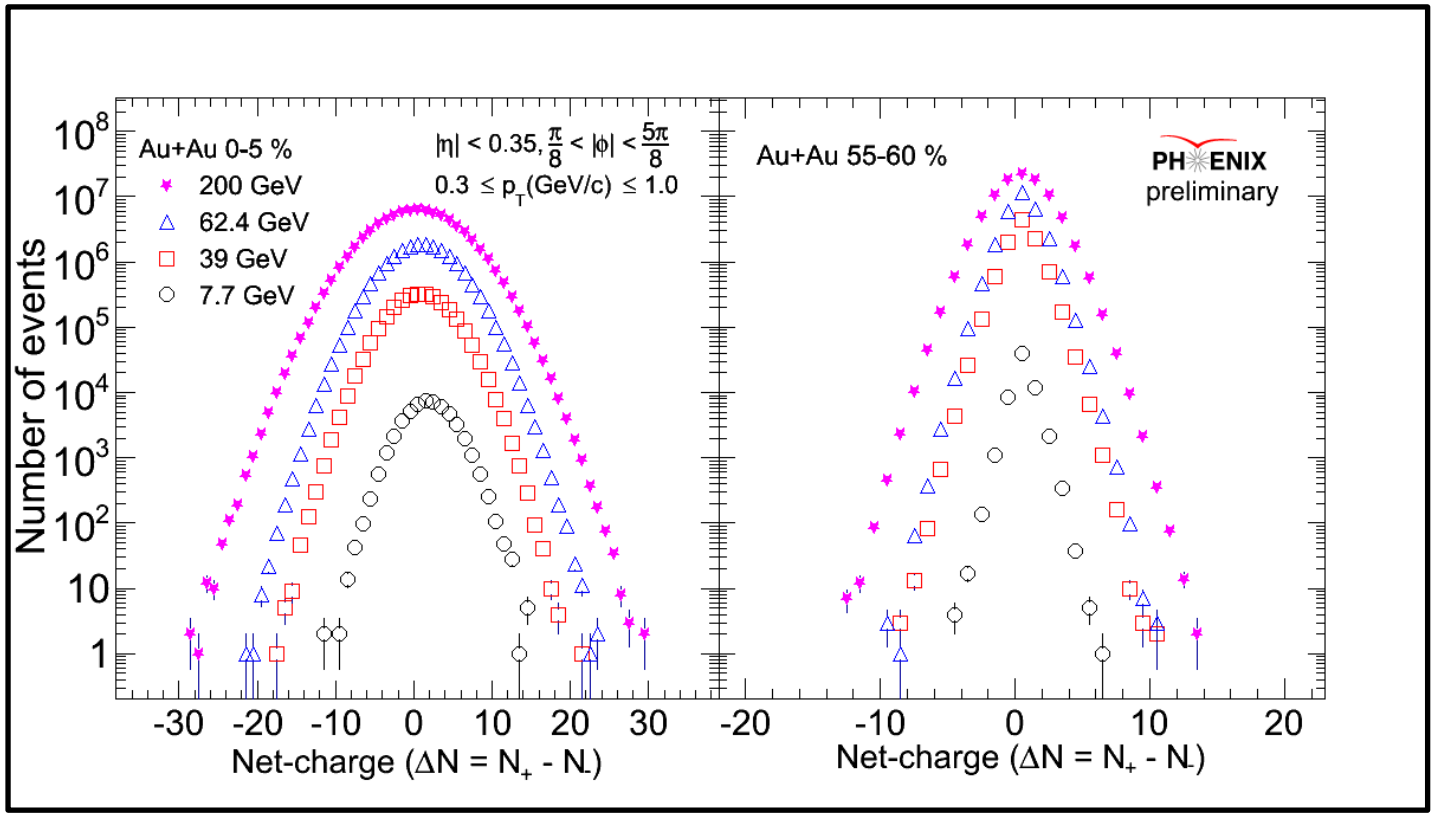
($1.5 < |\eta| < 2.8$ [outer])

- **Centrality bin width correction**
- **Stat. error estimation**

→using Delta theorem

X. Luo, J.Phys. G39 (2012) 025008

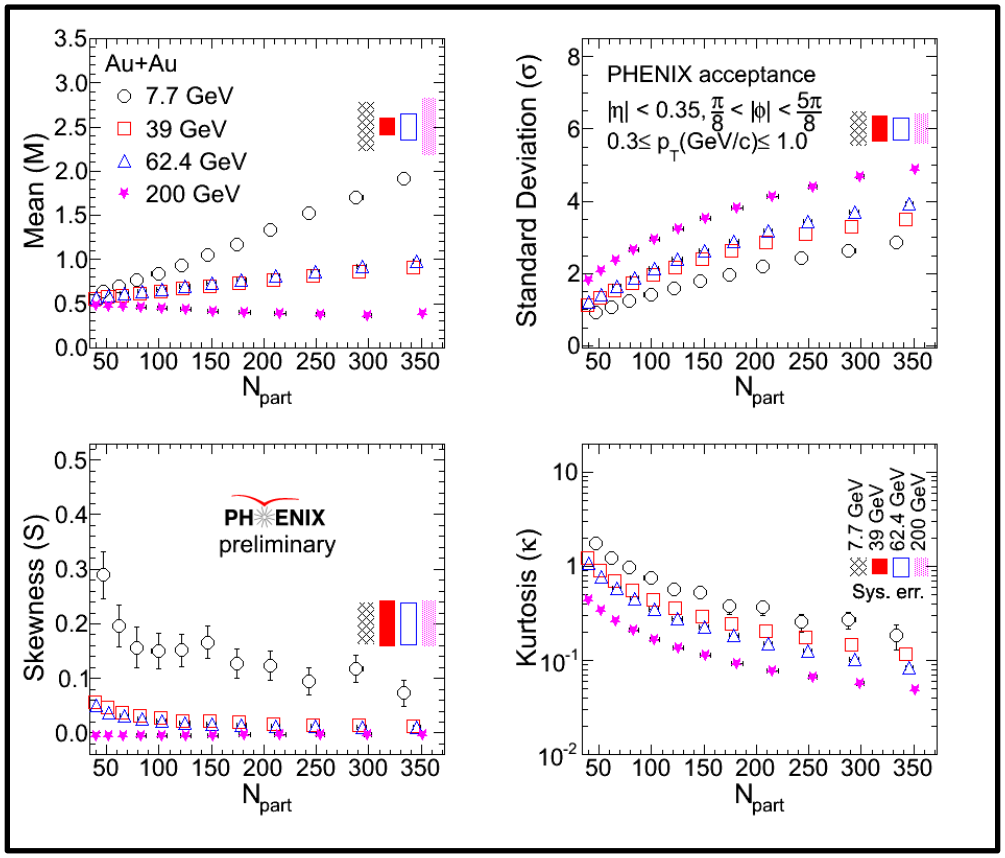
Raw Net-charge distributions



Datasets covers several orders of magnitude
Distributions are symmetric around zero

Centrality dependence of various moments

- M increases as we go higher to lower energy
- σ increases with energy and centrality
- S and κ increase with decreasing beam energy
- S and κ decrease from peripheral to central collisions

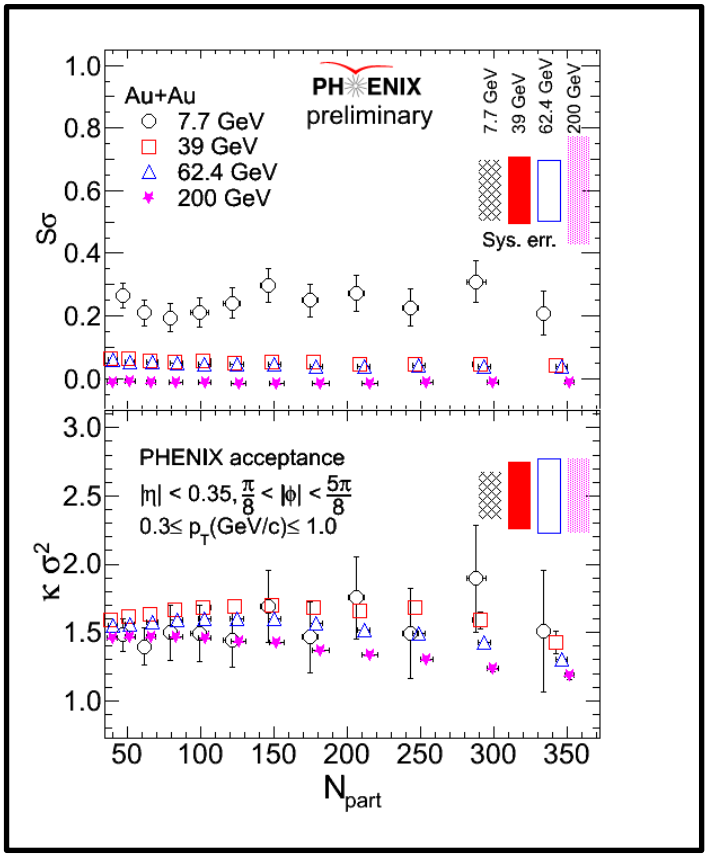


Systematic errors

$\sqrt{s_{NN}}$ (GeV)	7.7	39	62.4	200
M	11%	4%	6%	13%
σ	8%	6%	6%	7%
S	19%	20%	20%	21%
κ	22%	19%	23%	22%

Centrality dependence of product of the higher moments

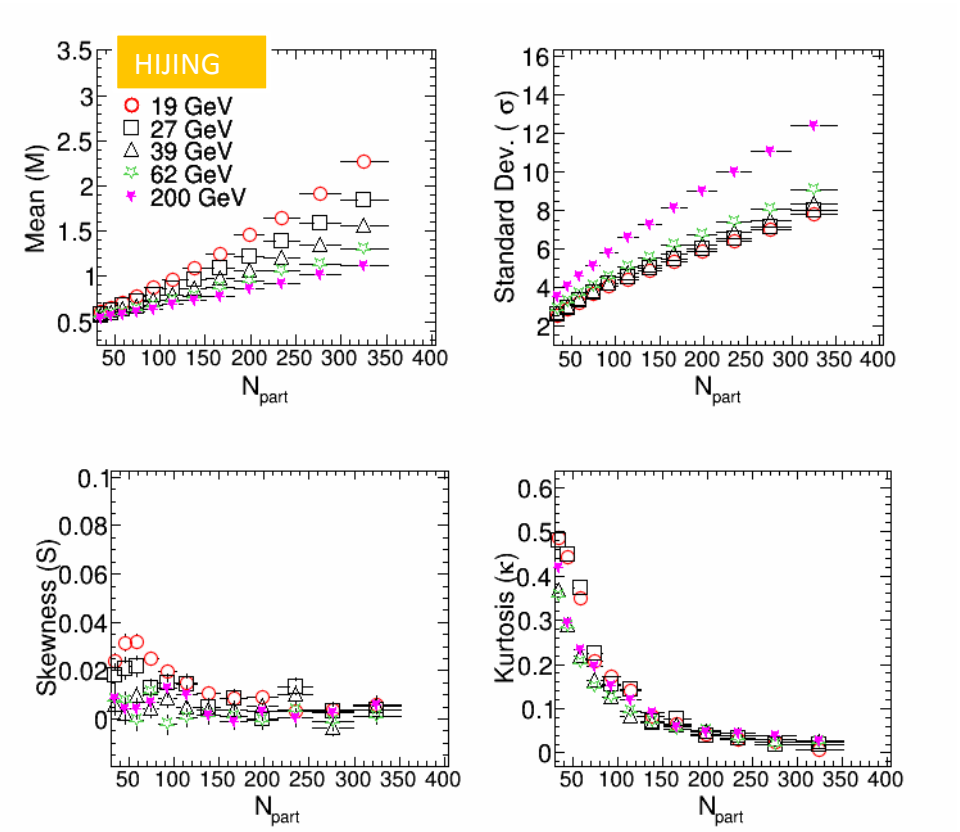
- ***$S\sigma$ and $\kappa\sigma^2$ have very weak centrality dependence***



Systematic errors

$\sqrt{s_{NN}}$ (GeV)	7.7	39	62.4	200
$S\sigma$	16%	18%	16%	29%
$\kappa\sigma^2$	7%	10%	11%	11%

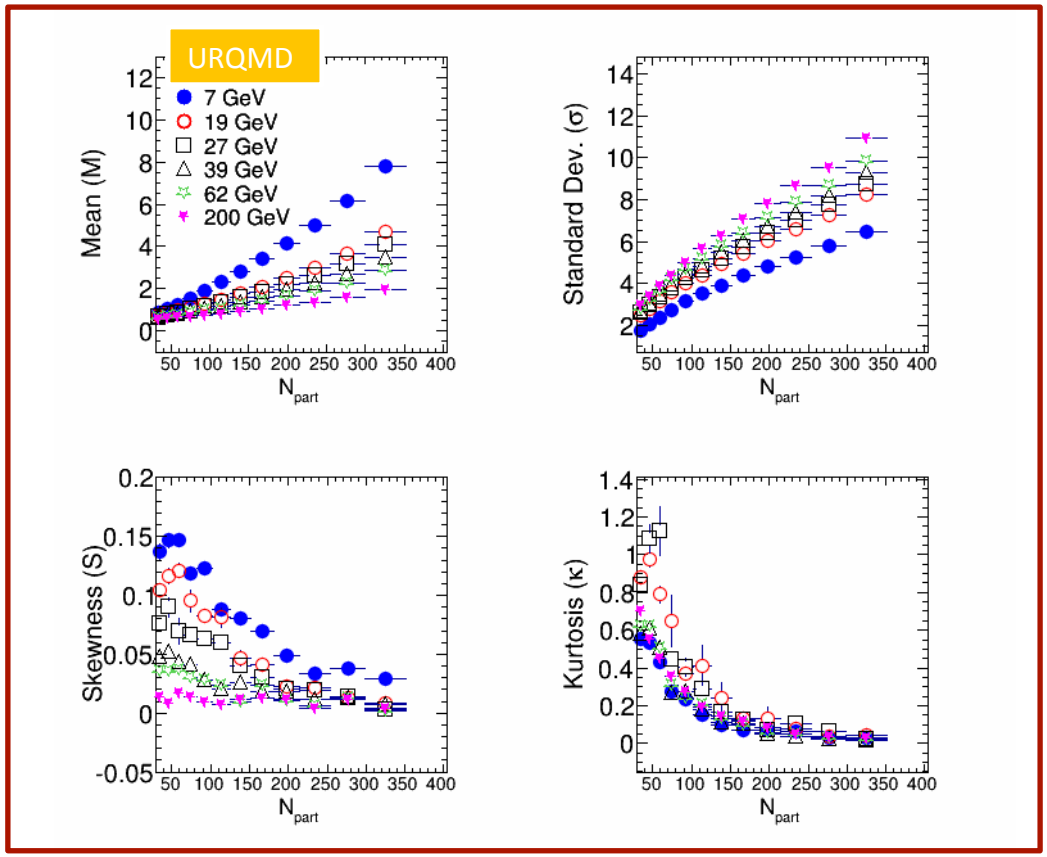
Model study: HIJING within PHENIX acceptance



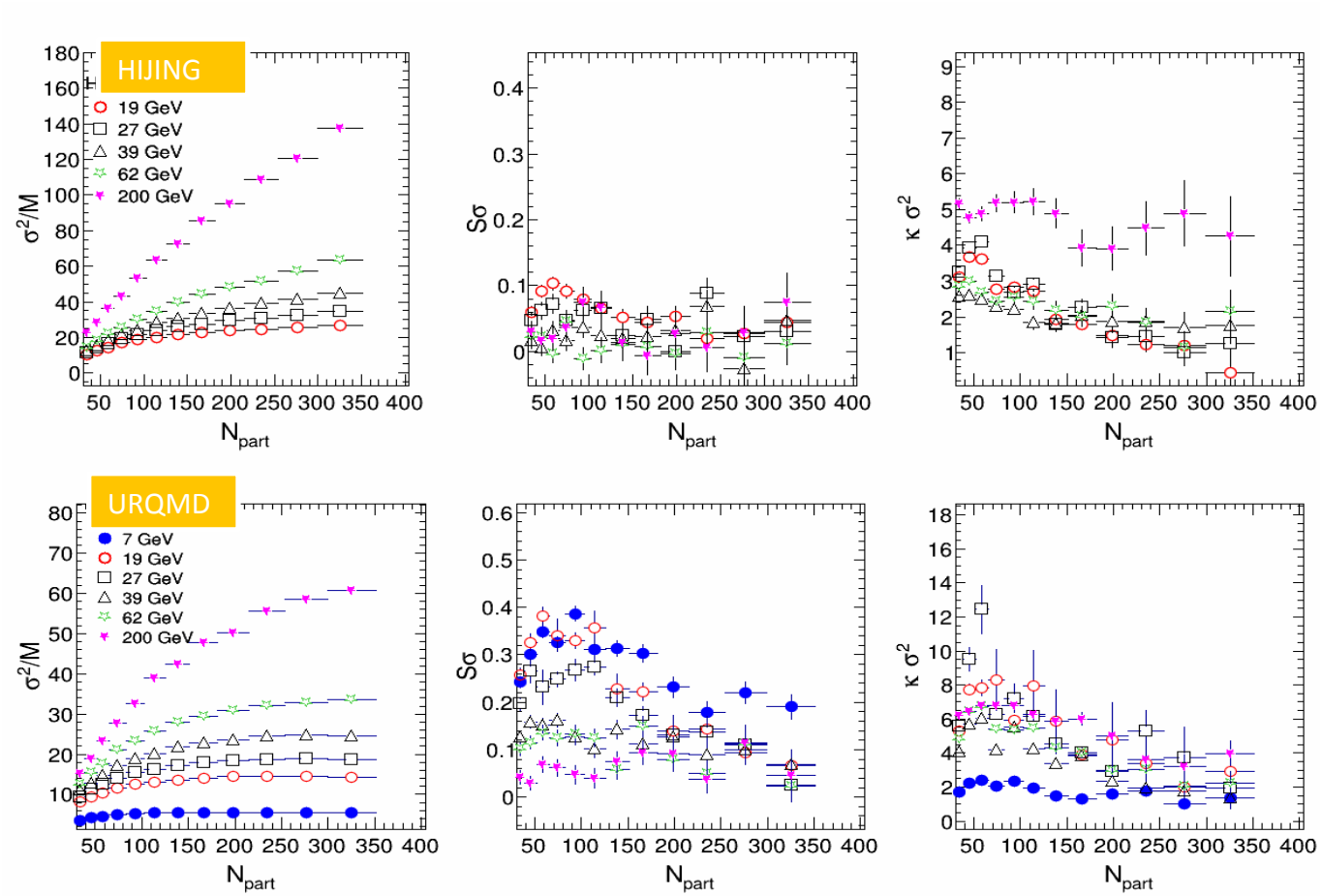
- M values increases with decreasing colliding energy
- σ values increase with energy and centrality
- S and κ have small dependence on energy

UrQMD within PHENIX acceptance

- M values increases with decreasing colliding energy
- σ values increase with energy and centrality
- S and κ have small dependence on energy

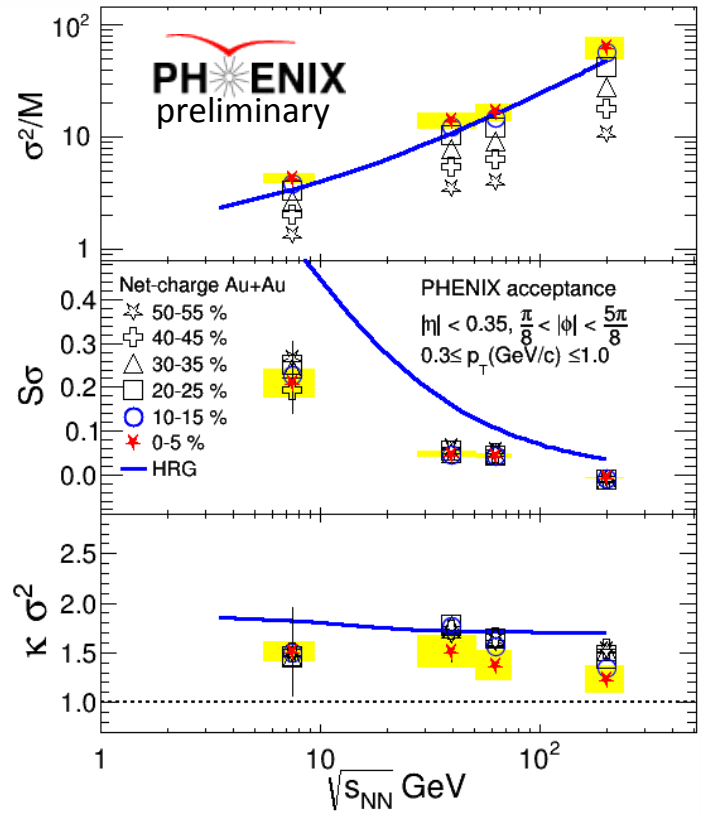


Models within PHENIX acceptance

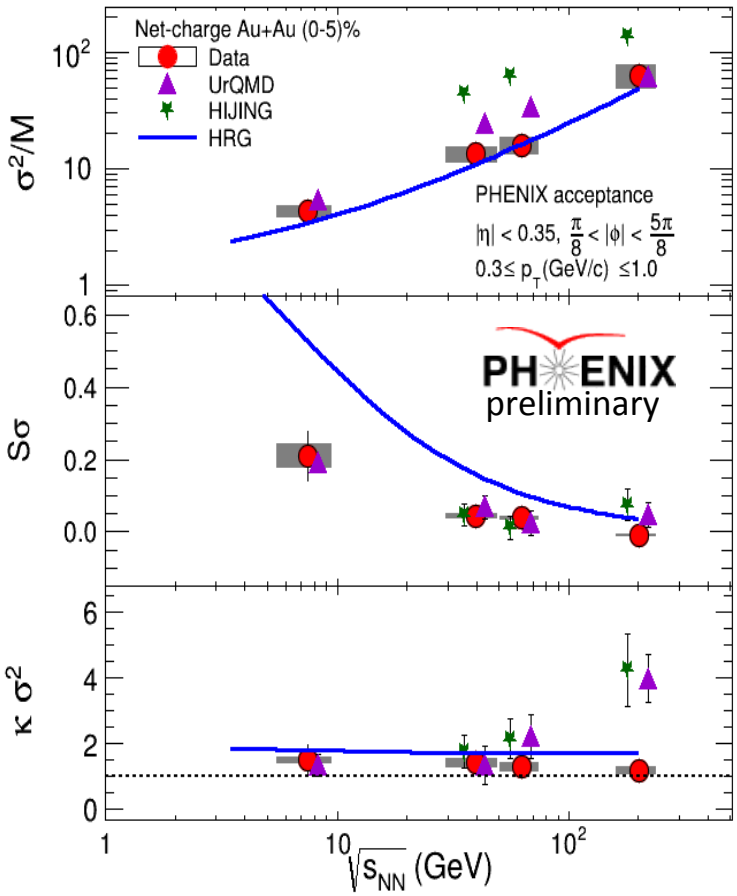


Centrality and energy dependence

- σ^2/M increase with increase in colliding energies and centrality
- $S\sigma$ and $\kappa\sigma^2$ are independent of centrality



Comparison of moments:Data vs. model



σ^2/M

- increase with increase in colliding energies
- Follows the HRG predictions for all the energies

$S\sigma$

- decreases with increasing colliding energy
- At higher energies Comparable with the model predictions
- At lower energies experimental values are lower than HRG predictions.

$\kappa\sigma^2$

- No energy dependence observed in data also supported by HRG predictions
- HRG predictions are Consistently higher with data
- Comparable with HIJING and URQMD except for 200 GeV

Conclusion

- Fluctuation of net-charge have been measured at different $\sqrt{s_{NN}}$ (7.7, 39, 62.4 and at 200 GeV)

- Net-charge
  - σ^2/M increase with colliding energies
  - $S\sigma$ values increase with decreasing energies.
  - $\kappa\sigma^2$ is independent of colliding energies.

- No significant excess in the moments of net-charge is observed compared to UrQMD, HIJING or HRG predictions.

- So far, PHENIX observes no sign of CP.
  It will be interesting to see 19.6 and 27 GeV results of net charge from PHENIX.