Higher order net-proton number cumulants dependence on the centrality definition and other spurious effects

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Sombun, S. *et al.* J.Phys. G45 (2018) no.2, 025101

Outline

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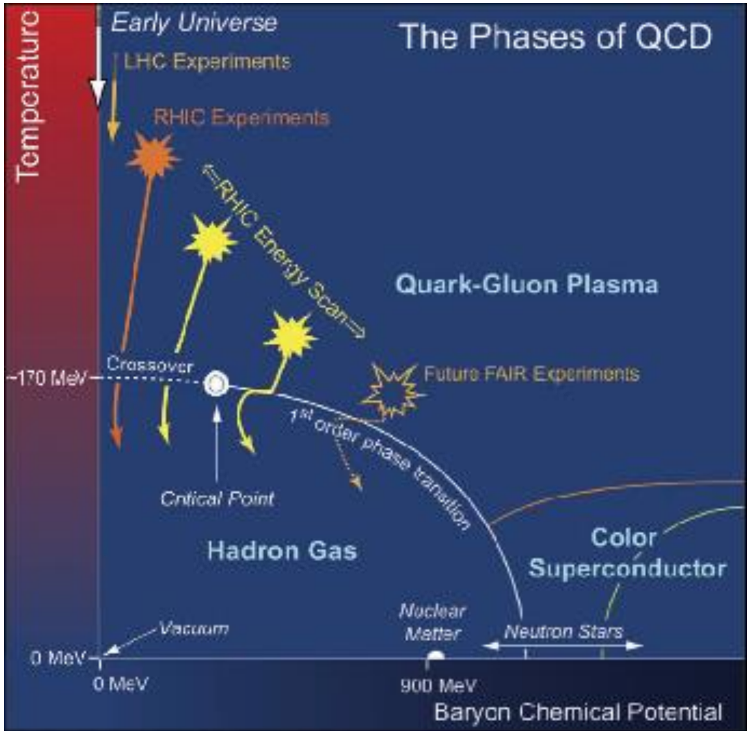
- ❖ Method
- ❖ Results
  - Dependence on centrality determination
  - Effects of acceptance
  - Effects of efficiency
- ❖ Conclusion

Introduction

- **Study QCD phase structure**:
  Search for the signals of possible phase boundary
  - The first order phase transition
  - Search for the possible QCD Critical Point

⇨ event-by-event fluctuations of conserved quantities
"**Cumulants**"



https://physics.stackexchange.com/questions/27033/phase-diagram-of-simplified-qcd

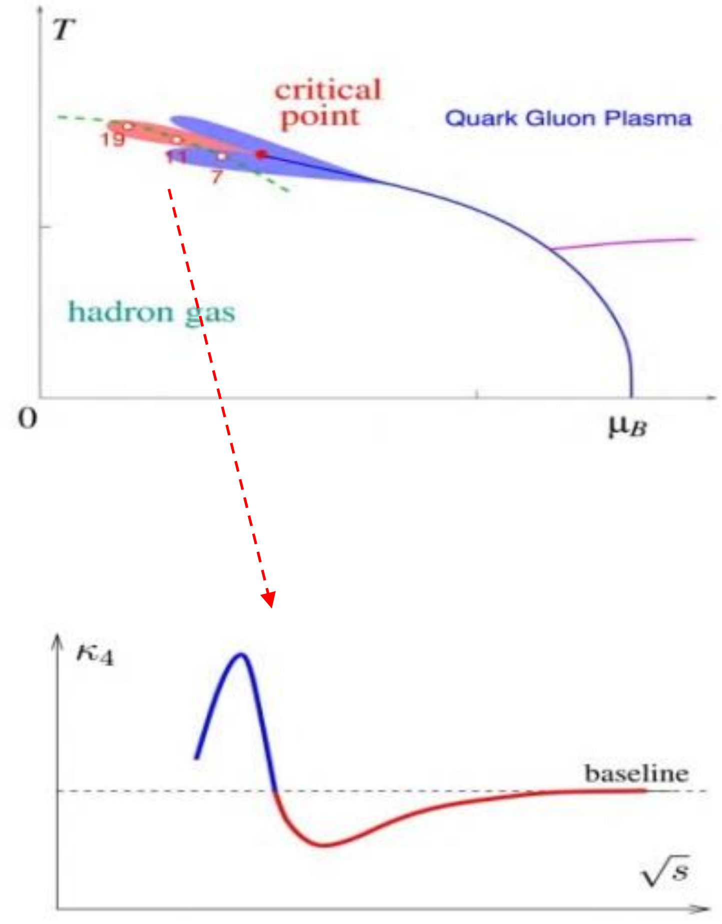
Introduction

- Higher order cumulants (e.g. net-baryon, net-charge and net-strangeness)

  - diverging susceptibilities

  - diverging correlation length

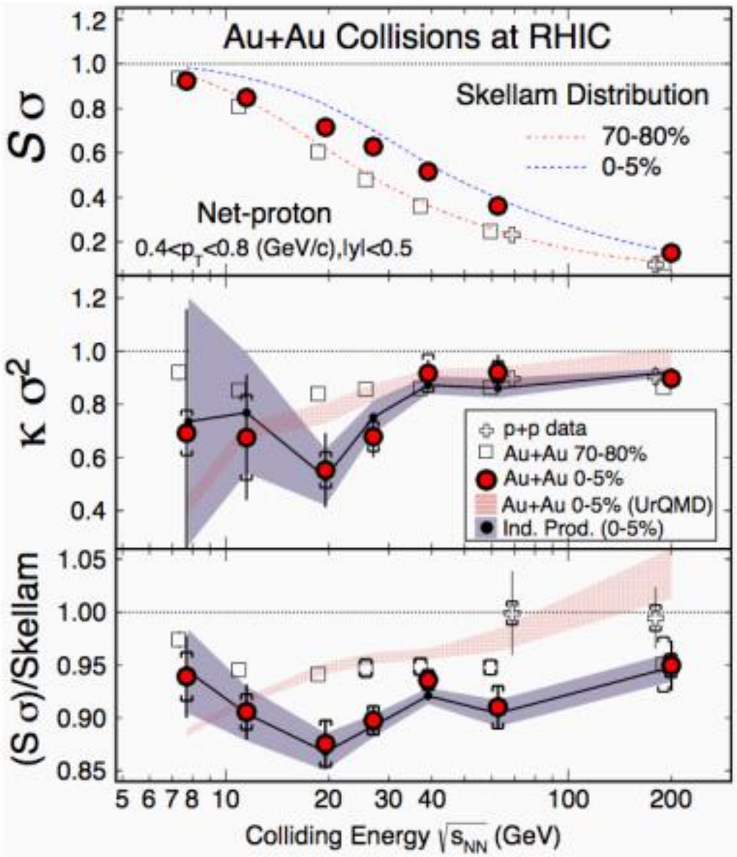
- leads to non-monotonic bahaviour with collision energy.



Stephanov, M. A. (2011).Phys. Rev. Lett., 107:052301.

Introduction

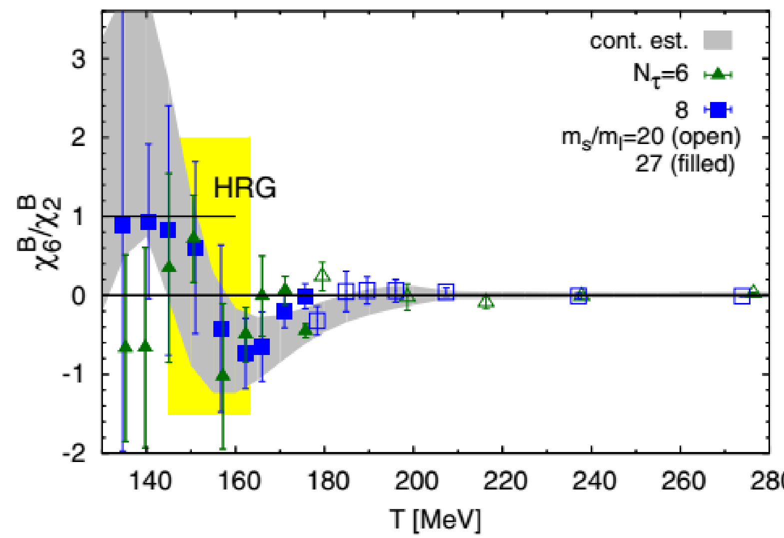
The STAR experiment at RHIC



- Cumulants ration show non-monotonic energy dependence of $\kappa\sigma^2$.

STAR Collaboration (Adamczyk, L. *et al.*) Phys.Rev.Lett. 112 (2014) 032302

Lattice QCD



- The result showed a non-monotonic behavior close to transition temperature T_c

Bazavov, A. *et al.* Phys.Rev. D95 (2017) no.5, 054504

Introduction

The UrQMD model

- The Ultra relativistic Quantum Molecular Dynamics **(UrQMD)** model.
  - Dynamics is based on hadrons and strings.
  - Simulation of p+p, p+A and A+A collisions.
  - Exploration of RHIC-BES energy range.

S. A. Bass *et al.*, Prog. Part. Nucl. Phys. **41**, 255 (1998).
M. Bleicher *et al.*, J. Phys. G **25**, 1859 (1999).

Method

Calculation of cumulant ratios of net-proton number

In the grand-canonical ensemble for the pressure of thermal system is related to the logarithm of partition function

$$P = \frac{T}{V}\ln Z(T,V,\mu)$$

The cumulants (C) are connected to the susceptibility (χ) of the system

$$\chi_n = \frac{\partial^n (P/T^4)}{\partial(\mu/T)^n} = \frac{1}{VT^3}C_n$$

Finally, we focus on ratios of cumulants

$$\frac{C_2}{C_1} = \frac{\langle \delta N^2 \rangle}{\langle N \rangle} = \frac{\sigma^2}{M}$$

$$\frac{C_3}{C_2} = \frac{\langle \delta N^3 \rangle}{\langle \delta N^2 \rangle} = S\sigma$$

$$\frac{C_4}{C_2} = \frac{\langle \delta N^4 \rangle}{\langle \delta N^2 \rangle} - 3\langle \delta N^2 \rangle = \kappa\sigma^2$$

where

$$(\delta N) = N - \langle N \rangle,\ N \text{ is net-proton number}$$

Method

- We simulate Au+Au collisions at beam energy 7.7 GeV with impact parameter (0 < b <15 fm) by using UrQMD model.

- **Centrality determination**, we classify collisions into 10 centrality bins and each centrality bin has 10% of the total number of events.
  - The number of participants (N_{part}).
  - The number of charged particles (N_{charge}).
  - The number of participants in projectile ($N_{part\text{-}projectile}$).

- We calculate the cumulants for a fixed N_{part}, N_{charge} and $N_{part\text{-}projectile}$ and then average the cumulants over all N_{part}, N_{charge} and $N_{part\text{-}projectile}$ in a given centrality bin. The ratios of cumulants are then taken as ratios of averages.

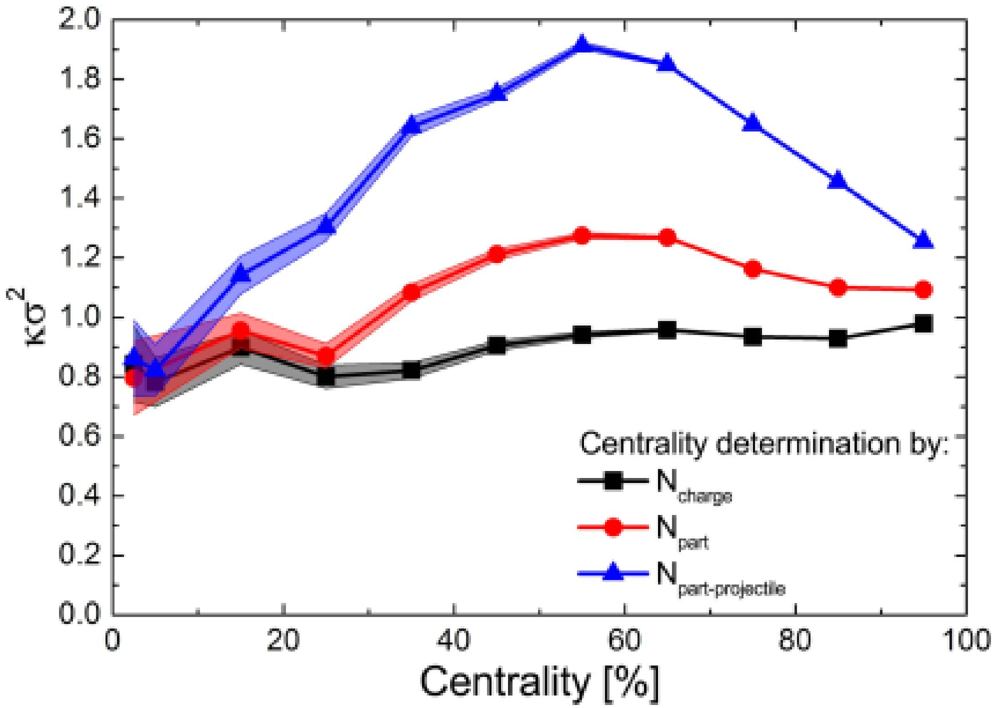
Results

- Dependence on centrality determination.
- Effects of acceptance.
- Effects of efficiency.
  1. The effect of centrality determination efficiency.
  2. The effect of 75% proton efficiency.

Results

Dependence on centrality determination

➡ transverse momentum $0.4 < p_T < 0.8 GeV$, mid-rapidity $|y| < 0.5$

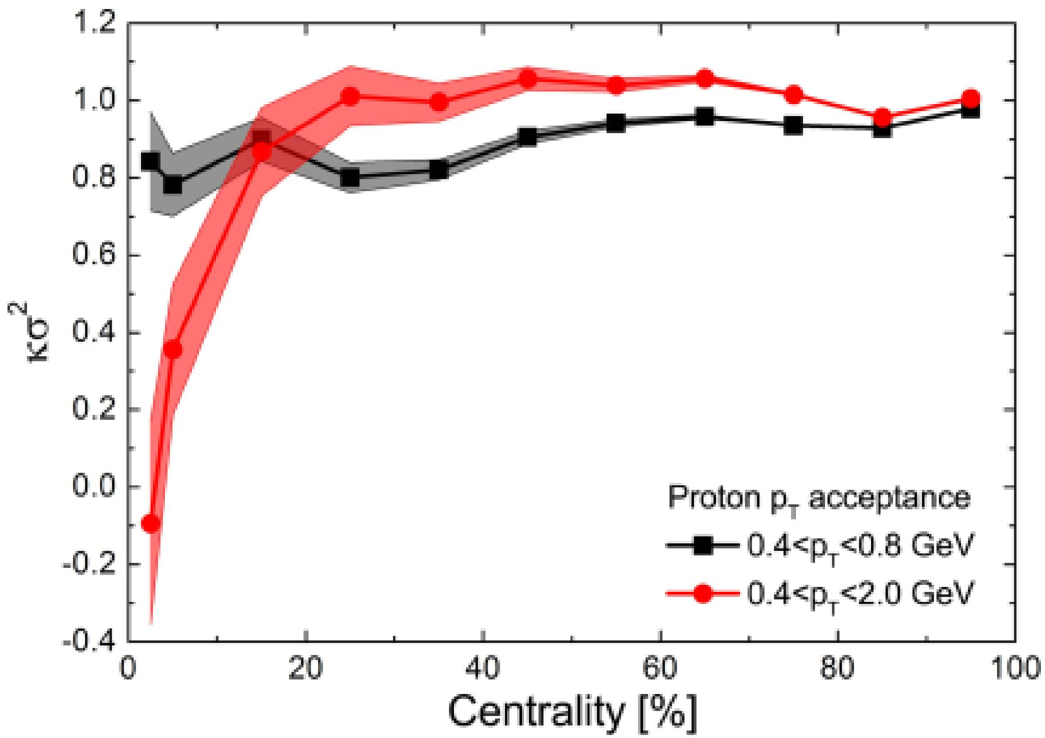


- Sizeable effect of volume fluctuations.
- Strongest effect if only projectile participants are used.

The net-proton kurtosis as function of centrality, which is defined by three different quantities, the number of charged particles, the number of participants or the number of participants in the projectile hemisphere.

Results

Effects of acceptance



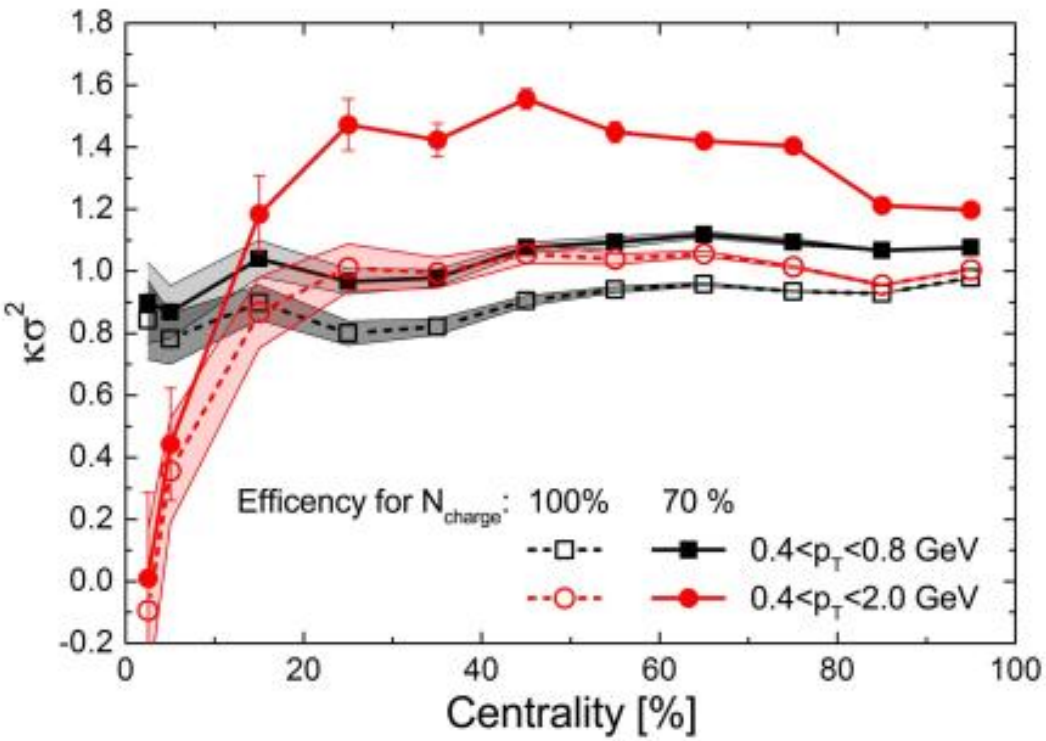
- Suppressed fluctuations in smaller windows.
- Effect of conservation laws for very central collisions.

The net-proton kurtosis as function of centrality (defined by N_{charge}) for two different p_T acceptance selections.

Results

Effects of efficiency

1. The effect of centrality determination efficiency.



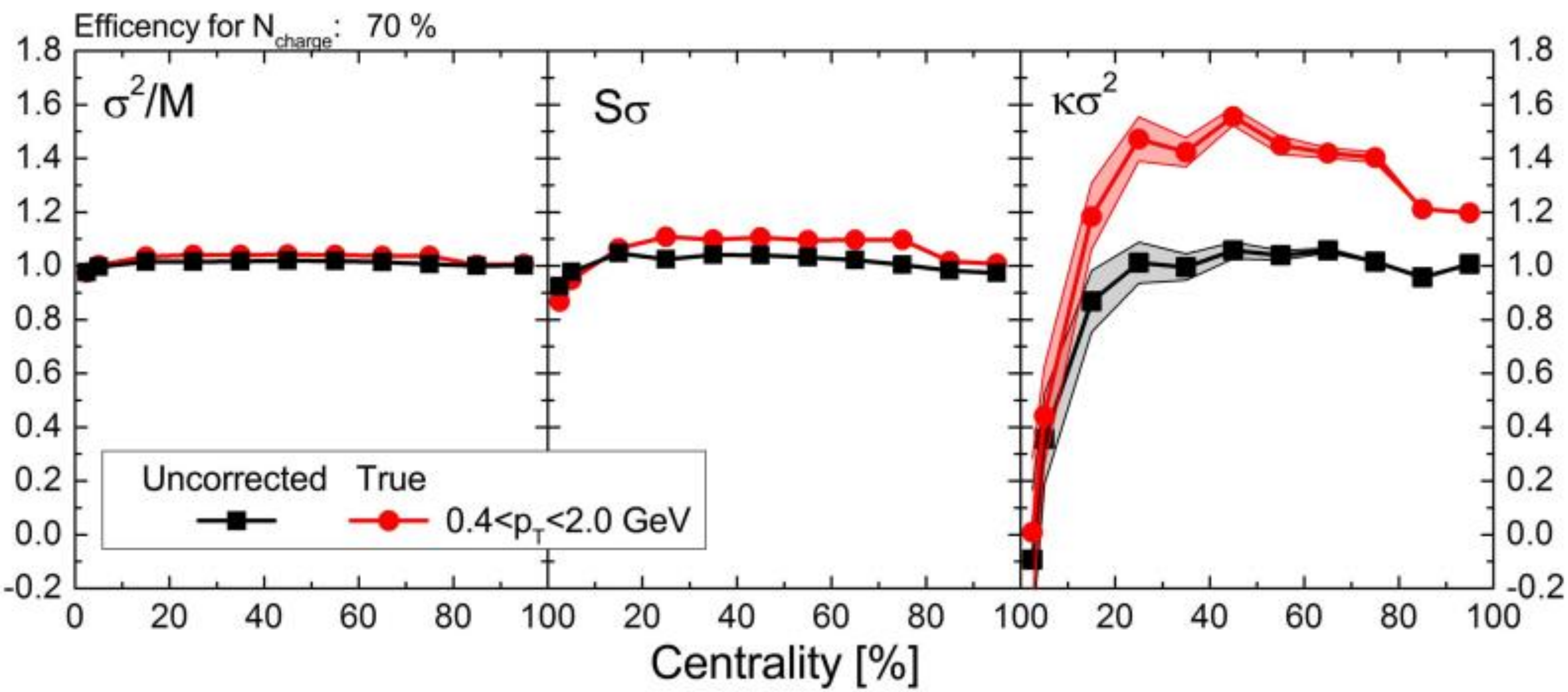
- low efficiency increases fluctuations.
- mixing of events with different centrality.
- bin width correction not sufficient.

Kurtosis of the net-proton number in two different p_T acceptance bins (black squares and red circles). We compare results with full efficiency for N_{charge} (open symbols) with results where we assume a 70% efficiency for N_{charge} (full symbols).

Results

Effects of efficiency

2. The effect of 75% proton efficiency.



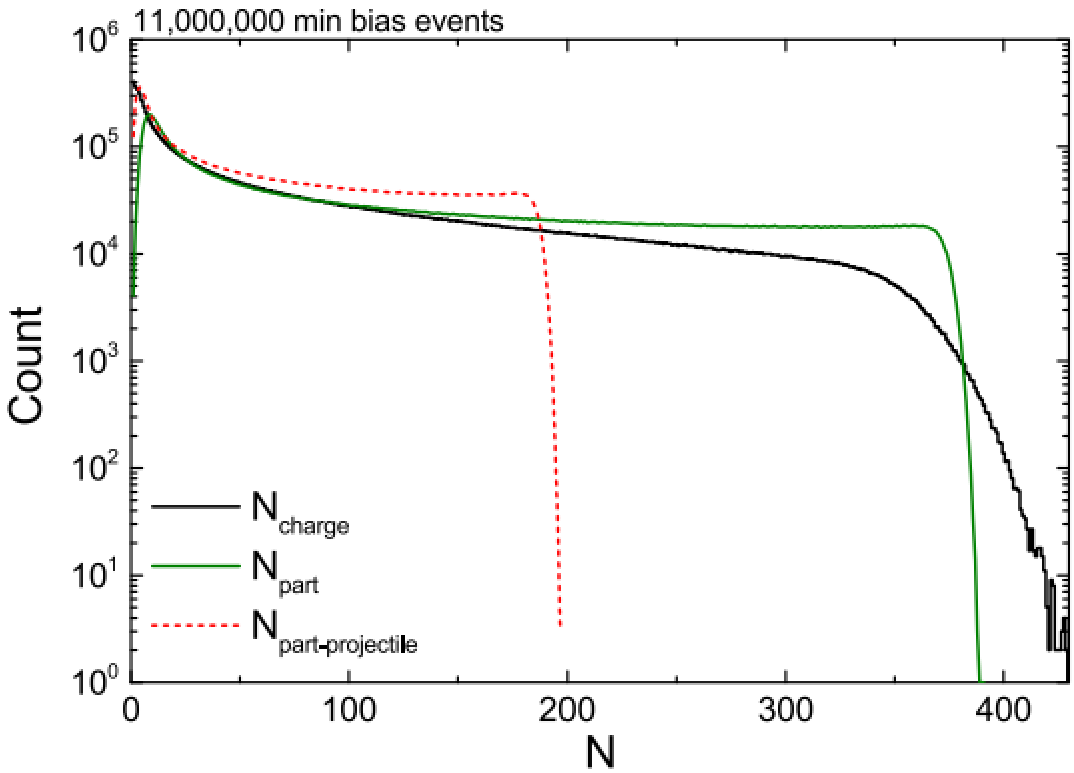
Variance, Skewness and Kurtosis of the net-proton number for a 70% N_{charge} efficiency. We compare results with full efficiency for protons (red circles) with results where we assume a constant efficiency for protons (black squares).

Conclusion

The calculation of kurtosis has to consider the effect of

- **Dependence on centrality determination**
- We show that the centrality determination given different result in kurtosis. We found that the centrality defined by N_{charge} has smallest volume fluctuation.
- **Acceptance**
- The wider range of transverse momentum will give smaller kurtosis at most central collision.
- **Efficiency**
- The 70 % efficiency of N_{charge} that define centrality will increase the kurtosis.
- The smaller efficiency of proton will poissonize the kurtosis.

Thank you
for
your attention !



Distributions of N_{charge}, N_{part} and $N_{part\ projectile}$ - for Au+Au collisions at a beam energy 7.7 GeV.