Dynamical cumulant ratios of net and total proton multiplicity distributions at STAR

Zhiming Li

(for the STAR Collaboration)

Institute of Particle Physics

Central China Normal University, Wuhan, China

1. Motivation
2. Data sample
3. Preliminary results at RHIC
4. Summary

1. Motivation

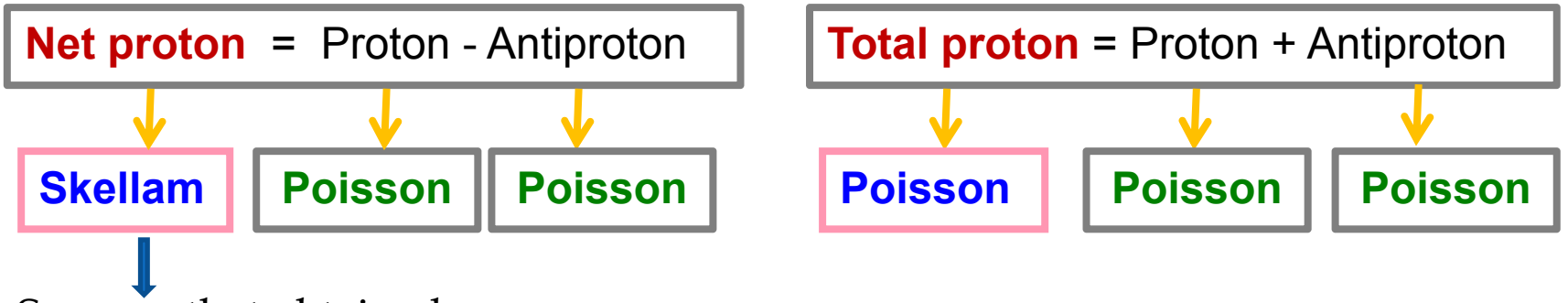
➢ Why dynamical cumulant ratios:

Suggestions:

Critical related part of higher cumulant ratio is that raw (directly measured) one subtract Poisson-like statistical part.

Lizhu Chen, et al., J. Phys. G: Nucl. Part. Phys. 38, 115004 (2011).
M. Stephanov , Phys. Rev. Lett. 107, 052301 (2011).
C. Athanasiou, K. Rajagopal, and M. Stephanov, arXiv:1006.4636;
M. Stephanove and K. Redlich, CPOD2011 talks.

➢ Poisson-like statistical fluctuation:



Same as that obtained from HRG model.

P.Braun-Munzinger, et al, arXiv:1107.4267.

➢ Dynamical cumulant ratios:

Define,

Dynamical ratio = Raw ratio – Poisson statistical part

Lizhu Chen, et al., J. Phys. G: Nucl. Part. Phys. 38, 115004 (2011).
C. Pruneau, et al, PRC66, 044904(2002);
STAR Coll. PRC68, 044905(2003); STAR Coll. PRC79, 024906(2009).

Raw ratios:

N: net-proton, or total proton.

Variance: $\sigma = \sqrt{\left\langle \left(N - \langle N \rangle \right)^2 \right\rangle}$

Skewness: $S = \dfrac{\left\langle \left(N - \langle N \rangle \right)^3 \right\rangle}{\sigma^3}$

Kurtosis: $\kappa = \dfrac{\left\langle \left(N - \langle N \rangle \right)^4 \right\rangle}{\sigma^4} - 3$

Poisson statistical parts:

- For net proton, ratios of Skellam distribution :

$$\sigma_{stat} = \sqrt{\langle N_p \rangle + \langle N_{\bar{p}} \rangle},$$

$$S_{stat} = \frac{\langle N_p \rangle - \langle N_{\bar{p}} \rangle}{\left(\langle N_p \rangle + \langle N_{\bar{p}} \rangle\right)^{3/2}}, \qquad (S\sigma)_{stat} = \frac{\langle N_p \rangle - \langle N_{\bar{p}} \rangle}{\langle N_p \rangle + \langle N_{\bar{p}} \rangle},$$

$$\kappa_{stat} = \frac{1}{\langle N_p \rangle + \langle N_{\bar{p}} \rangle}, \qquad \left(\kappa\sigma^2\right)_{stat} = 1$$

- For total proton, ratios of Poisson distribution :

$$\sigma_{stat} = \sqrt{\langle M \rangle}, \qquad (M = N_p + N_{\bar{p}})$$

$$S_{stat} = \frac{1}{\sqrt{\langle M \rangle}}, \qquad (S\sigma)_{stat} = 1,$$

$$\kappa_{stat} = \frac{1}{\langle M \rangle}, \qquad \left(\kappa\sigma^2\right)_{stat} = 1$$

- Statistical parts are mostly determined by means (except some products are unity), which are energy and centrality dependent.

➢ Expected critical behavior of dynamical ratios :

4^{th} ratios:

4^{th} dynamical cumulant ratios will be universally negative when CP is approached from crossover side. Moreover, at the same √s, dynamical Kurtosis decreases at more peripheral collisions, and sign change to positive at low √s.

M. Stephanov , Phys. Rev. Lett. 107, 052301 (2011).
R. Gavai and S. Gupta, Phys. Lett. B 696, 459 (2011).
Lizhu Chen, et al., arXiv:1010.1166.

3^{rd} ratios:

Sign change near the critical point: negative when $T<T_c$
positive when $T>T_c$.

M. Akasawa, et al., PRL 103, 262301 (2009);
Lizhu Chen, et al., arXiv:1010.1166.

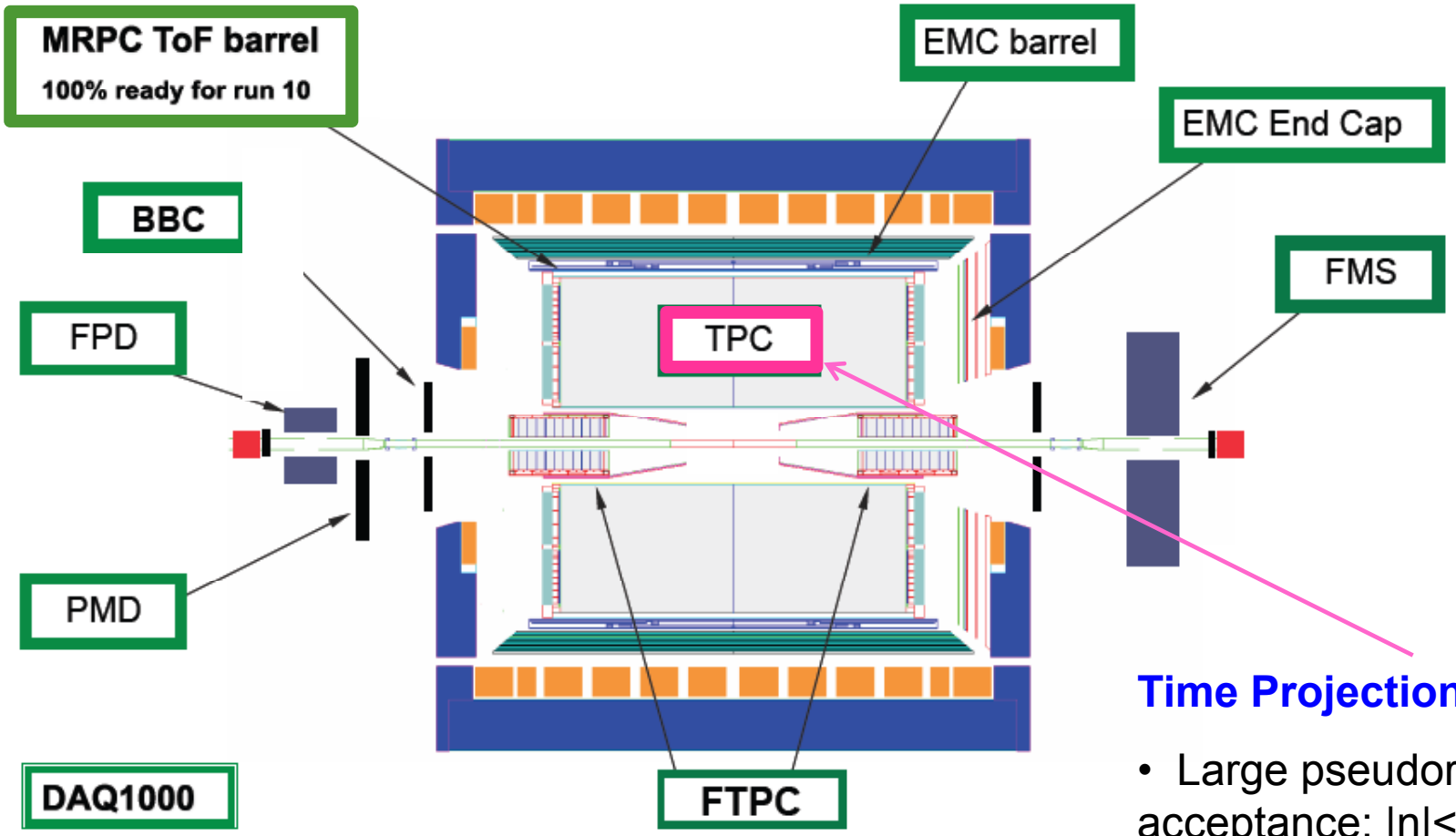
2^{nd} variance:

Observe deviations from HRG model could be due to the proximity of the freeze-out and cross-over regions. The deviations should be expected at central collisions and higher incident energies.

P.Braun-Munzinger, et al., arXiv:1107.4267.

2. Date sample

STAR Detector



Full azimuthal particle identification!

Time Projection Chamber

- Large pseudorapidity acceptance: |η|<1
- PID: Ionization Energy Loss (dE/dx).

Data set and cuts

Au + Au Collisions at 200, 62.4, and 39 GeV

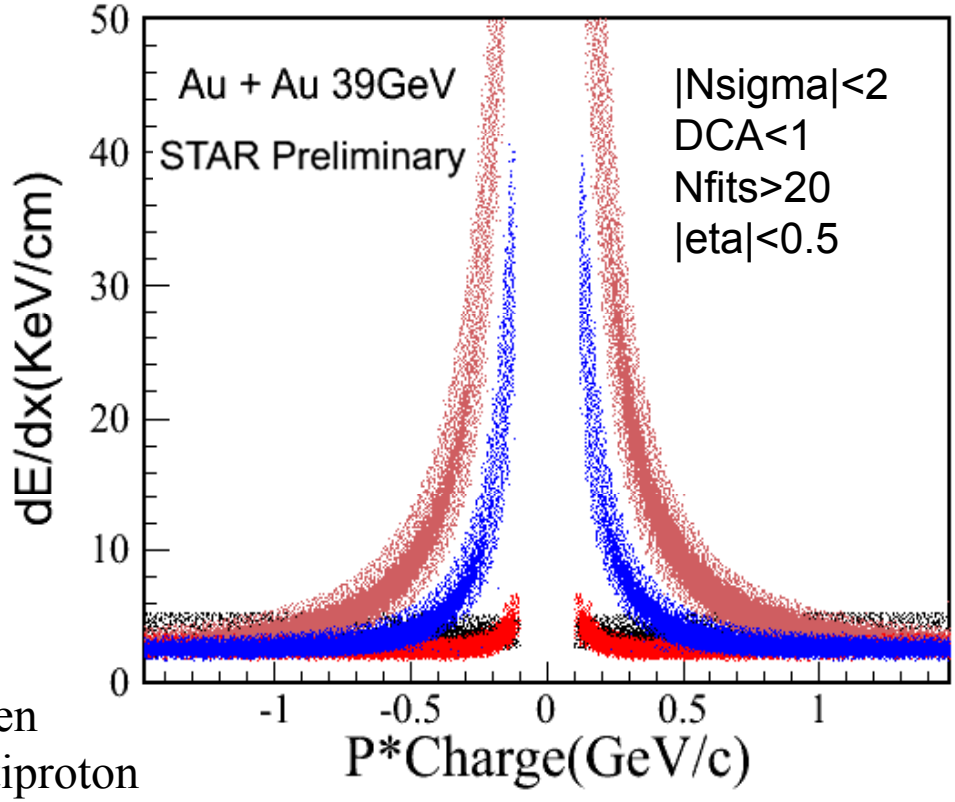
RHIC Beam Energy Scan (BES) data at 2010

❖ Track Quality Cut

a:DCA<1.0
b: Nfits>20
c: Nfits/NFitPoss>0.52

❖ Particle Identify (PID) with TPC:

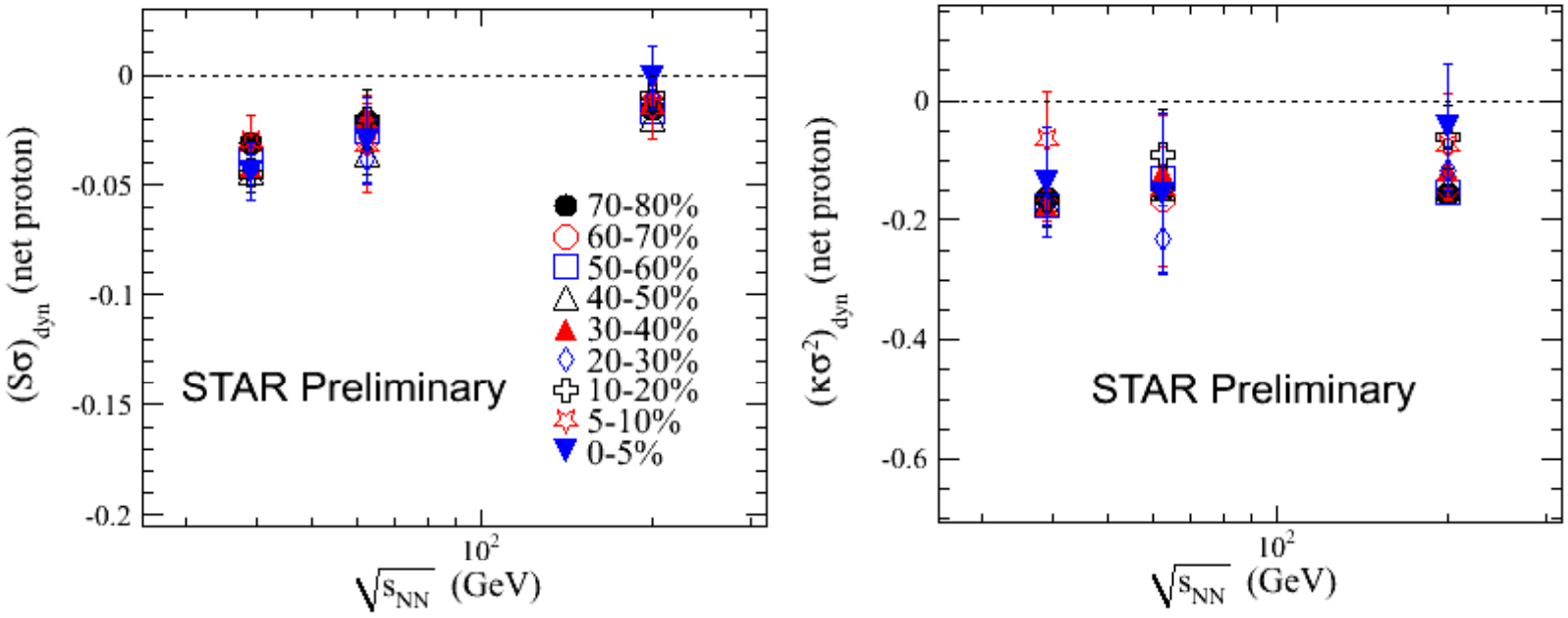
Proton/Antiproton:
|NsigmaProton|<2.0,
|y|<0.5, $0.4<p_T<0.8$ GeV/c



Systematic effects: auto-correlation between centrality selection and selected proton/antiproton region, PID methodology, and statistical error estimation.

3. Preliminary results at RHIC

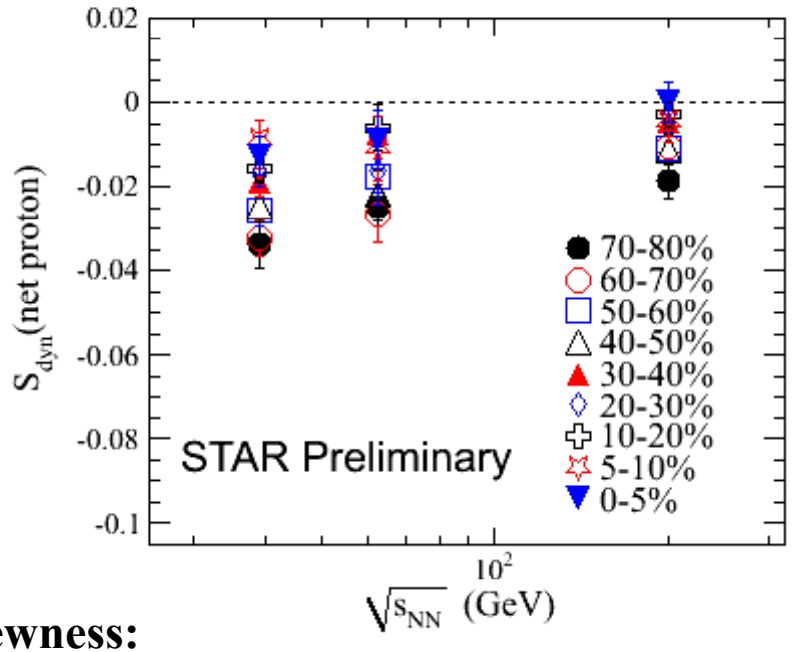
- 3rd and 4th dynamical cumulant product ratios:

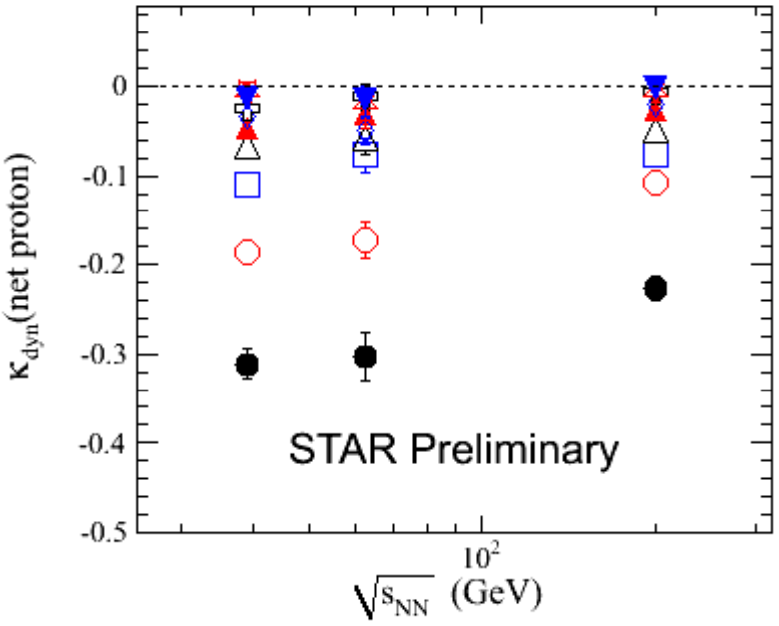


- For dynamical Sσ, deviation from zero get larger at lower energies.
- Centrality independent.
- Negative in most energies and centralities. No sign change is observed for 3rd and 4th ratios.

M. Akasawa, et al., PRL 103, 262301 (2009);
M. Stephanov , Phys. Rev. Lett. 107, 052301 (2011).

➢ Dynamical Skewness and Kurtosis:





Skewness:

- Deviations from zero get larger at peripheral collisions, or lower energies.
- No sign change ! - Lattice/effective/3D-Ising models

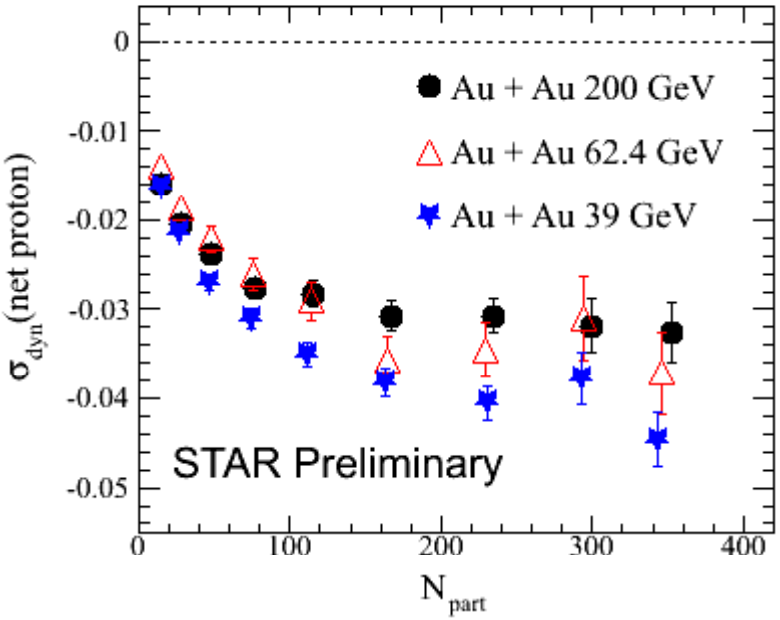
R. V. Gavai, et al, PLB 696, 459(2011);
M. Akasawa, et al., PRL 103, 262301 (2009);
Lizhu Chen, et al., arXiv:1010.1166.

Kurtosis:

- Weaker energy dependence in more central collisions, but clear energy dependence in peripheral collisions. Larger deviation at peripheral collisions.
  - possible reasons: volume (size) effect
- No sign change at low energy.

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

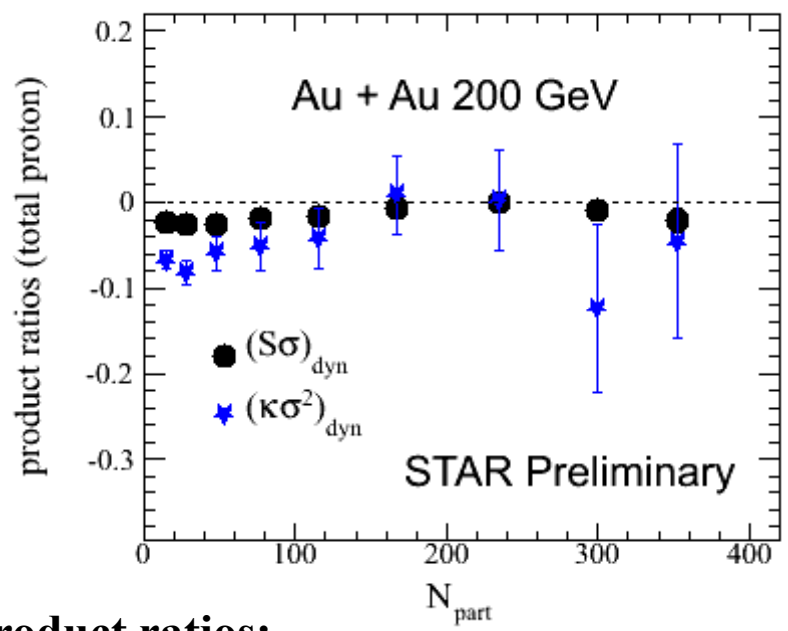
➢ Dynamical Variance:

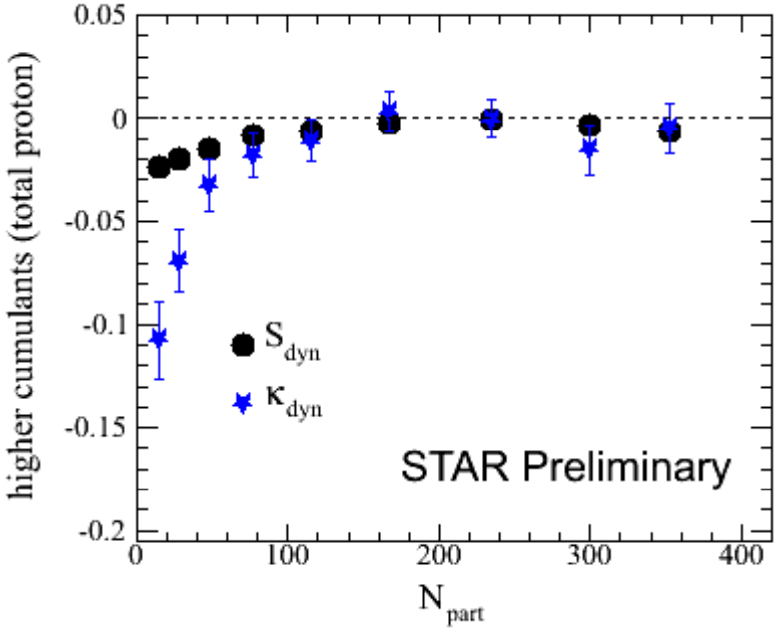


- Negative in all centralities and energies, i.e., net proton distribution is narrower than that of independent Poisson-like statistics.
- Larger deviations from zero at more central collisions – consistent with the prediction.
- Larger deviations in lower incident energies – in contrary with the expectation.

P.Braun-Munzinger, et al., arXiv:1107.4267
K. Redlich, CPOD2011 talk at 9th Nov.

➢ Dynamical cumulants ratios of total proton at 200 GeV





Product ratios:

- Negative in different centralities.
- Centrality independent within errors.

Skewness/Kurtosis:

- Close to zero in central collisions.
- Deviations from zero get larger in more peripheral collisions.

- General behaviors of total proton are same as those of net proton.

4. Summary and outlook

- Energy dependence of dynamical $S\sigma$, $\kappa\sigma^2$, σ , S, and κ of Au + Au collisions at 39, 62.4 and 200 GeV are presented.
  - Dynamical $S\sigma$ and $\kappa\sigma^2$: Negative in most energies and centralities. Independent of centrality.
  - Dynamical S and κ: deviations from zero get larger in more peripheral collisions, or lower energies. No sign change!
  - Dynamical σ, larger deviations at central collisions, or lower incident energies.
- The centrality dependence of total proton at 200 GeV are similar to those of net proton.

Outlook:

Results from all the other RHIC/BES energies are ongoing.