Dynamical kurtosis of net and total protons at STAR

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Abstract

Higher cumulant of baryon number is suggested to be a good probe of Critical Point in relativistic heavy ion collisions. However, the statistical fluctuations are not negligible and it should be subtracted from the directly measured cumulants, so we introduce the dynamical cumulant ratios. Moreover, it is suggested by Misha Stephanov that the sign of the dynamical net proton kurtosis will change to be negative when the critical point is approached from the crossover side of the phase transition.

In this work we present the energy and centrality dependence of dynamical net and total proton kurtosis for Au + Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27, 39, 62.4 and 200 GeV at RHIC. The sign behavior of dynamical kurtosis of net proton is discussed and compared to those of total proton. The results are also compared with AMPT model calculations.

1. Measurement

◆ **Higher cumulant ratios:**

Standard deviation: $\sigma = \sqrt{\langle (N-\langle N\rangle)^2\rangle}$ Skewness: $S = \frac{\langle (N-\langle N\rangle)^3\rangle}{\sigma^3}$

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

N: the net or total proton number in an event

$\langle\cdots\rangle$: the average over the event sample

◆ **Definition of dynamical kurtosis:**

Dynamical kurtosis = measured kurtosis – Poisson statistical part

Lizhu Chen, et al., J. Phys. G: Nucl. Part. Phys. 38, 115004 (2011).
M. Stephanov , arXiv: 1104.1627; Phys. Rev. Lett. 107, 052301(2011).
C. Athanasiou, K. Rajagopal, and M. Stephanov, arXiv:1006.4636;
C. Athanasiou, K. Rajagopal, and M. Stephanov, arXiv:1008.3385.

◆ **Poisson statistical parts:**

The statistical fluctuation comes from the finite number of particles. They are usually presented by a Poisson distribution. If the numbers of protons and antiprotons are two independent Poisson distributions, the net-proton number is a Skellam distribution, and the total-proton number is a new Poisson distribution.

➢ For net-proton, the ratios of Skellam distribution:

$$\kappa_{stat} = \frac{1}{\langle N_p\rangle + \langle N_{\bar p}\rangle}, \quad S_{stat} = \frac{\langle N_p\rangle - \langle N_{\bar p}\rangle}{(\langle N_p\rangle + \langle N_{\bar p}\rangle)^{3/2}}$$

➢ For total-proton, the ratios of Poisson distribution:

$$\kappa_{stat} = \frac{1}{\langle N_p\rangle + \langle N_{\bar p}\rangle}, \quad S_{stat} = \frac{1}{\sqrt{\langle N_p\rangle + \langle N_{\bar p}\rangle}}$$

2. Expected critical behavior from the Sigma model

By describing fluctuations of the order parameter field σ near the critical point, the calculations of the Sigma model indicates and predicts that:

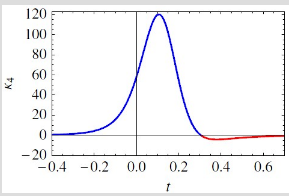
M. Stephanov, Phys. Rev. Lett. 107, 052301 (2011).
M. Stephanov, Phys. Rev. Lett. 102, 032301 (2009).

◆ Dynamical kurtosis is universally negative when the critical point is approached from the crossover side of the phase separation line.

critical contribution of the cumulant in the σ field

$$\langle(\delta N)^4\rangle_c = \langle N\rangle + \langle\sigma_V^4\rangle_c\left(\frac{gd}{T}\int_p \frac{n_p}{\gamma_p}\right)^4 + \cdots$$

measured cumulant   Poisson contribution



◆ The negative kurtosis should be firstly observed in more peripheral collisions.

$t = \frac{T - T_c}{T_c}$ is the reduced temperature

3. Data sample

Au+Au collisions from 7.7 to 200 GeV at RHIC/BES of year 2010 and 2011

◆Particle Identification with Time Projection Chamber:

Protons/antiprotons are identified by ionization energy loss measured in |y|<0.5, 0.4<p_T<0.8 GeV/c.

◆Centrality definition:

Use the multiplicity in $|\eta|$<0.5 but excluding the protons/antiprotons to avoid auto-correlations.

◆Statistical error estimation:

Delta theorem method

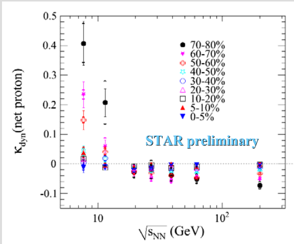
X. Luo, J. Phys. G 39, 025008 (2012) [arXiv: 1109.0593]

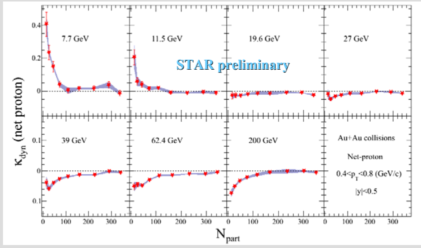
Used statistics

$\sqrt{s_{NN}}$ (GeV)	No. of Events (0-80% central)
7.7	~2M
11.5	~7M
19.6	~15M
27	~30M
39	~87M
62.4	~47M
200	~242M

4. Results and discussions

Dynamical kurtosis of net-proton at RHIC/BES





The bracket and the shadowed areas represent the systematic uncertainties.

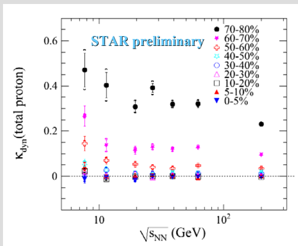
➢ Below 19.6 GeV, the dynamical kurtosis is positive within errors in peripheral collisions, and increase towards more peripheral collisions.

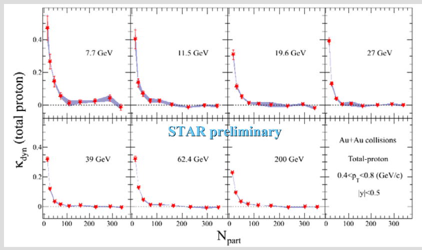
➢ Above 19.6 GeV, the dynamical kurtosis turns to be negative in peripheral collisions.

➢ This sign change behavior is consistent with the prediction of the Sigma model.

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

Dynamical kurtosis of total-proton at RHIC/BES



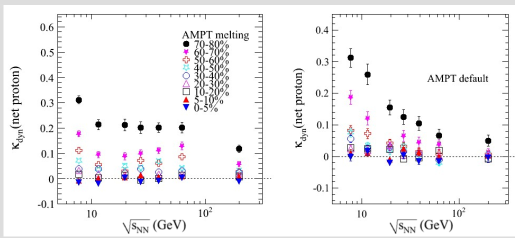


➢ We observe a positive dynamical kurtosis for peripheral collisions at all energies.

➢ In central collisions, the dynamical kurtosis is around zero at all incident energies.

➢ In contrary to net-proton we do NOT observe a sign change for total-proton.

Dynamical net-proton kurtosis of the AMPT model at RHIC/BES energies



➢The dynamical kurtosis is positive in non-central collisions at all incident energies.

➢ No sign change is observed for two settings of the AMPT model.

5. Summary

➢ We find that in peripheral collisions, the sign of dynamical kurtosis of net-proton changes from negative to positive when incident energy decreases, consistent with the predicted trend of the Sigma model.

➢ In the contrary, the sign of dynamical kurtosis of total-proton keeps positive at all incident energies and centralities.

➢ From AMPT model calculations where no critical behavior is included, the dynamic kurtosis for net-proton is found to be positive in non-central collisions for all energies.