

Precision measurement of Fifth and Sixth Order Fluctuation of (Net-)proton Multiplicity Distributions in Au+Au Collisions from BES-II Program at RHIC

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We report precision measurements of fifth and sixth-order cumulants and factorial cumulants of (net-)proton multiplicity distribution in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 - 27 GeV measured by the STAR experiment from second phase of Beam Energy Scan program (BES-II) at RHIC. Using the high statistics data collected with upgraded detectors, we select protons and antiprotons at mid-rapidity |y| < 0.5 within $0.4 < p_{\tau}$ (GeV/c) < 2.0. The dependence of measured cumulants and factorial cumulants on the collision energy are presented. Measurements are compared with the corresponding calculations from the lattice QCD, QCD based model FRG, hadronic transport model UrQMD and a thermal hadron resonance gas model.

1. Introduction					4. Detector and measurement			
* QCD Phase Diagram:	LHC	SPS	AGS	B. Mohanty, N. Xu, an	Xiv:2101.09210	* Detector upgrade:	* <u>Centrality:</u>	* Measurement:
		3-3	AGS			Improved dE/dV		



emperatu 80 Hadron Gas 3. High $\mu_{\rm B}$: possible 1st order phase 500 transition.

(MeV)

- RHIC FAIR Quark-Gluon Plasma NICA 1500 1000 Baryonic Chemical Potential μ_{B} (MeV)
- 4. Goal: study the nature of the QCD phase transition.
- ◆ Observables: → Net-proton cumulants

 $C_1 = \langle N \rangle$, $C_2 = \langle (\delta N)^2 \rangle$, $C_3 = \langle (\delta N)^3 \rangle$, $\delta N = N - \langle N \rangle$ $C_4 = \langle (\delta N)^4 \rangle - 3 \langle (\delta N)^2 \rangle^2, \quad C_5 = \langle (\delta N)^5 \rangle - 5 \langle (\delta N)^3 \rangle \langle (\delta N)^2 \rangle$ $C_6 = \langle (\delta N)^6 \rangle - 15 \langle (\delta N)^4 \rangle \langle (\delta N)^2 \rangle - 10 \langle (\delta N)^3 \rangle^2 + 30 \langle (\delta N)^2 \rangle^3$

Proton factorial cumulants

- Improved dE/dX measurements.
- Larger η coverage: $|\eta| < 1.0$ to $|\eta| < 1.6$
- Reimuli3X: Charged particle multiplicity excluding proton and antiproton within $|\eta| < 1.6$
- Event-by-event uncorrected net-proton distribution.



5. Results

* Net-proton cumulant ratio C_1/C_1 and C_2/C_2 :



* Proton factorial cumulants K_A , K_5 , K_6 :

A _					
4	STAR Preliminary	Au+Au Collisions			
-	-	proton			
	г	y <0.5	14.1		
2	-	0.4 < p _r (GeV/c)<2.0			
I					





A. Bzdak et al, PRC98, 054901 (2018), PRC100, 051902(R) (2019)

3. Data set details

Au+Au, energy (GeV)	7.7	9.2	11.5	14.6	17.3	19.6	27
Events BES-II (10 ⁶)	45	78	116	178	116	270	220

Around 7-18 times increase in statistics compared to BES-I.

• Uncertainty reduced by factor of 3.2 (stat) and 13.2 (sys) for C_6/C_2 (0-40%) at 7.7 GeV.



order. No significant indication of twocomponent structure in proton distribution as expected for a 1st order phase transition.

M. S. Abdallah et al. (STAR Collaboration), Phys. Rev. Lett. 128, 202303 (2022) M. S. Abdallah et al. (STAR Collaboration), Phys. Rev. C 107, 024908 (2023). LQCD: A. Bazavov et al. Phys. Rev. D 101, 074502 (2020). FRG: W. j. Fu et al. Phys. Rev. D 104, 094047 (2021) HRG-CE: P. Braun-Munzinger et al. Nucl. Phys. A1008, 122141 (2021). UrQMD: M. Bleicher et al. J. Phys. G 25, 1859 (1999).



- 1. New and higher statistics measurements of hyper order cumulants ratios and factorial cumulants of (net-)proton distribution presented for Au+Au collisions at $\sqrt{s_{_{NN}}} = 7.7 - 27$ GeV.
- 2. Measurements of net-proton C_5/C_1 and C_6/C_2 and proton factorial cumulants κ_{A} , κ_{5} and κ_{6} for 0-40% and 70-80% centrality are close to zero within uncertainty.
- 3. Results compared with various models with and without QCD transition. No significant indications of two component shapes in proton distribution, as expected for a 1st order phase transition, observed.