Rapidity Dependence of Proton Higher-Order Cumulants in $\sqrt{s_{NN}}$ = 3.2 GeV Au+Au Collisions

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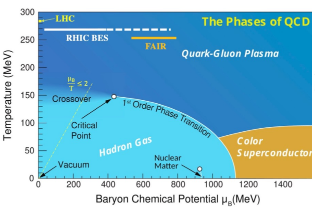
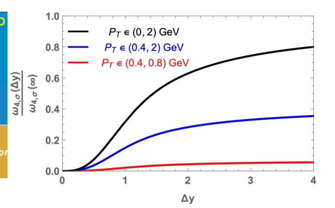
Abstract

Fluctuations of conserved quantities are proposed as useful observables to study the QCD phase structure including the search for the first-order phase boundary and critical point [2]. Lattice QCD calculations disfavor presence of a critical point for baryon chemical potential μ_B less than 450 MeV and few phenomenology model calculations have shown that the critical point could be at temperature of T ~ 90 - 120 MeV and baryonic chemical potential of μ_B ~ 500 – 650 MeV [3-7].

Rapidity dependence of the higher order cumulant ratios have been argued to be sensitive to the QCD critical point [2,8]. In this poster, we will report rapidity dependence of both higher order cumulants and factorial cumulants of proton multiplicity distribution, up to 6TH order from Au+Au collisions, at $\sqrt{s_{NN}}$ = 3.2 GeV ($\mu_B \sim 700$ MeV) from the STAR experiment at RHIC. Collision centrality and rapidity dependence of the measurements will be discussed. In addition, the results will be compared with the calculations from the hadronic transport model UrQMD.

1. Motivation

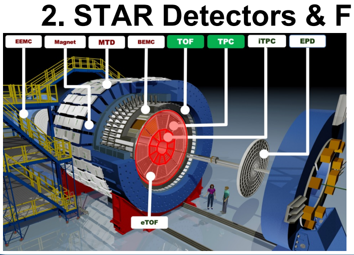


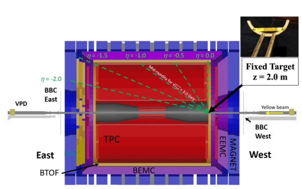


B. Ling and M.A. Stephanov, Phys. Rev. C 93, 034915 (2016)

1. Find the possible QCD critical point and 1st order phase boundary;
2. Should the critical behavior exist, a larger enhancement in fluctuations at wider rapidity and transverse momentum bins is expected;
3. STAR Fixed-Target (FXT) experiment allows us to scan from mid-rapidity to target rapidity, thus allows us to understand the dynamical evolution from hot medium to cold nuclear matter.

2. STAR Detectors & Fixed-Target Setup





3. Experimental Observables

Cumulants:

$\delta N = N - \langle N \rangle$, N is proton multiplicity in an event

$C_1 = \langle N \rangle$

$C_2 = \langle \delta N^2 \rangle$

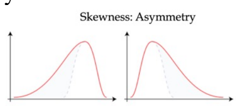
$C_3 = \langle \delta N^3 \rangle$

$C_4 = \langle \delta N^4 \rangle - 3\langle \delta N^2 \rangle^2$

$C_5 = \langle \delta N^5 \rangle - 10\langle \delta N^3 \rangle\langle \delta N^2 \rangle$

$C_6 = \langle \delta N^6 \rangle - 15\langle \delta N^4 \rangle\langle \delta N^2 \rangle - 10\langle \delta N^3 \rangle^2 + 30\langle \delta N^2 \rangle^3$

Skewness: Asymmetry



Skewness$= C_3/(C_2)^{\frac{3}{2}}$

Factorial Cumulants:

$\kappa_1 = C_1$

$\kappa_2 = -C_1 + C_2$

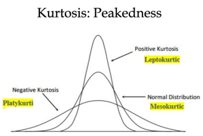
$\kappa_3 = 2C_1 - 3C_2 + C_3$

$\kappa_4 = -6C_1 + 11C_2 - 6C_3 + C_4$

$\kappa_5 = 24C_1 - 50C_2 + 35C_3 - 10C_4 + C_5$

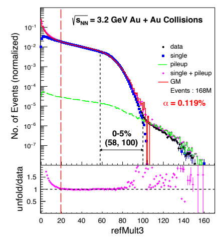
$\kappa_6 = -120C_1 + 274C_2 - 225C_3 + 85C_4 - 15C_5 + C_6$

Kurtosis: Peakedness

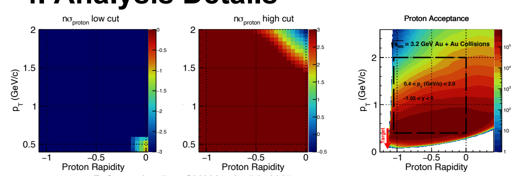


kurtosis$= C_4/(C_2)^2$

4. Analysis Details



T. Nonaka et al., *NIM A* 984, 164632 (2020)

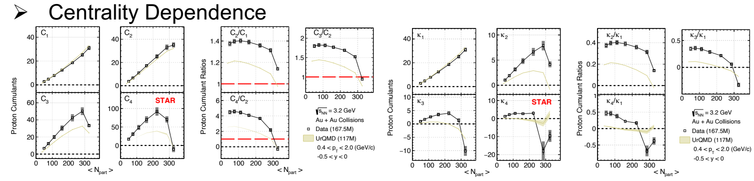


Z. Sweger's talk at QM2025, April 9, 2025

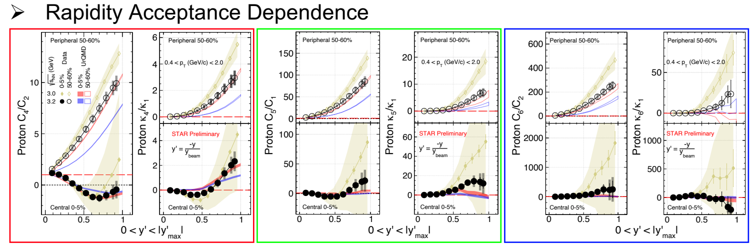
1. Pileup correction with unfolding method;
2. Select protons within a p_T and y dependence $n\sigma_{proton}$ range;
3. Scan proton rapidity from mid- to projectile rapidity.

5. Results

➢ Centrality Dependence



➢ Rapidity Acceptance Dependence



M. Abdallah, Phys. Rev. C 107, 024908 (2023)

1. New results from the $\sqrt{s_{NN}}$ = 3.2 GeV Au+Au collisions are shown as filled and open circles for central (0-5%) and peripheral (50-60%) collisions, respectively. Both statistical and systematic uncertainties are shown. For comparison, the published results of $\sqrt{s_{NN}}$ = 3.0 GeV Au+Au collisions are shown as diamonds and the yellow bands are systematic uncertainties;
2. In $\sqrt{s_{NN}}$ = 3.2 GeV Au+Au collisions, from mid- to projectile-rapidity, clear rapidity dependences are observed both proton cumulants and factorial cumulant ratios. Similar rapidity dependence has also been observed in the 3.0 GeV collisions;
3. Results from the hadronic transport model UrQMD qualitatively reproduce these dependence. Larger difference between experimental data and model calculations are seen at the projectile rapidity.

6. Summary

1. Strong centrality and rapidity dependence observed in proton (factorial) cumulant ratios in Au+Au collisions at $\sqrt{s_{NN}}$ = 3.2 GeV;
2. UrQMD qualitatively reproduces the centrality and rapidity dependence of proton (factorial) cumulant ratios. Deviations are seen in peripheral and high rapidity regions in central collisions.

7. References

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