Dynamical evolution of critical fluctuation and its observation

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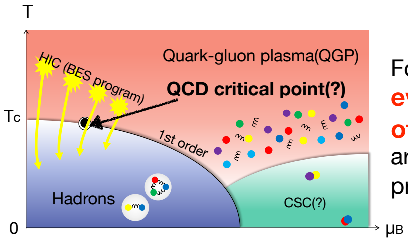
Sakaida et al., to appear soon

1. Purpose of this study



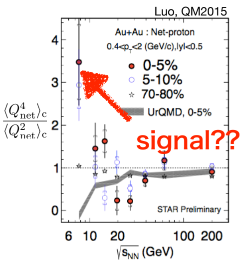
For exploring QCD critical point, **event-by-event fluctuations of conserved charges** are believed to be promising observables in HIC.

Purpose of this study

- To investigate time evolution of fluctuations of net-baryon number near QCD critical point.
- To propose a new signature among fluctuation observables.

2. Fluctuations in BES

Collision energy dependence of net proton cumulants@STAR(2015)



- Large fluctuations of conserved charges are expected near the QCD critical point
- Non-monotonicity in $\sqrt{s_{\rm NN}}$ dep. of the kurtosis is a signal of QCD critical point??

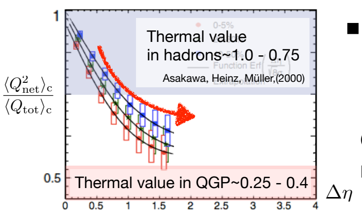
More understanding for fluctuation observables is needed!!

Thermal fluctuation@QCD critical point Asakawa, Ejiri, Kitazawa(2009); Stephanov(2009)

$\langle Q^2\rangle_c \sim \xi^2$ and $\langle Q^3\rangle_c \sim \xi^{4.5}, \langle Q^4\rangle_c \sim \xi^7$ + **sign change** with correlation length : $\xi \to \infty$

3. Rapidity window $\Delta\eta$ dependence

Variance of net-electric charge@ALICE(2013)



- For larger $\Delta\eta$, the value approaches the one **in QGP (earlier state in HIC)?!**

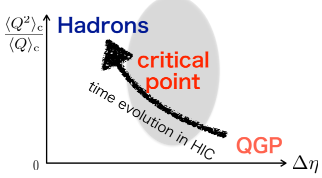
Why?

Conserved-charge fluctuations relax via diffusion!!

Relaxation time of diffusion : $\tau_{\rm eq} \sim q^{-2}$

q: large (small) ↔ $\Delta\eta$: small (large)
↔ $\tau_{\rm eq}$: short (long)
↔ **Past (present) info.** is reflected.

$\Delta\eta$ dep. reflects time history of HIC!



If system passes near the QCD critical point, its information might appear in $\Delta\eta$ dependence!

4. Dynamics near QCD critical point

Soft mode near the QCD critical point
= linear coupling between chiral condensate and conserved densities

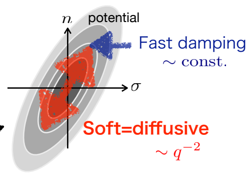
Fujii, Ohtani(2004); Son, Stephanov(2004)

TDGL eq. with coupling

$$\begin{pmatrix}\dot\sigma\\ \dot n\end{pmatrix} = -\begin{pmatrix}\Gamma_{\sigma\sigma} & \tilde\lambda_{\sigma n}q^2\\ \tilde\lambda_{\sigma n}q^2 & \lambda_{nn}q^2\end{pmatrix}\begin{pmatrix}\sigma\\ n\end{pmatrix} + \begin{pmatrix}\xi_\sigma\\ \xi_n\end{pmatrix}$$

- Chiral condensate σ (non-conserved) relaxes with time scale $\sim$ const..
- Net-baryon density n (conserved) relaxes with diffusive time scale $\sim q^{-2}$.

In the long wavelength limit ($q \to 0$), **two modes** are found.



Stochastic diffusion eq. (SDE) : $\partial_\tau n = D(\tau)\partial^2_\eta n - \partial_\eta \xi_n$

SDE is also used for descriptions of conserved charge in non-critical region!

Shuryak, Stephanov(2001)

5. Our model

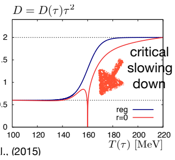
We employ **SDE** to describe time evolution of fluctuations of net-baryon in rapidity space. **(From QGP→QCD critical point→to thermal freeze-out)**

$$\partial_\tau n = D(\tau)\partial^2_\eta n - \partial_\eta \xi_n \xrightarrow{\text{solve}} \chi = \langle n^2\rangle_c$$

Diffusion coefficient

In critical region : $D \sim \xi^{-1.044}$ with $\xi \to \infty$

Other region : Thermal value in each state

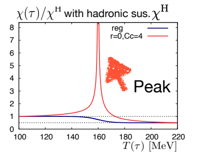


MS. et al.(2014): Aarts. et al.. (2015)

Susceptibility(thermal value of fluctuation)

In critical region : $\chi \sim \xi^{1.96}$ with $\xi \to \infty$

Other region : Thermal value in each state

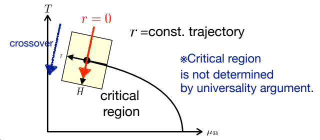


Asakawa. et al.(2000):

Static universality class of QCD critical point : 3D Ising, Dynamic : model H (Liquid-gas) Hohenberg, Halperin(1977)

*Assume 1D boost invariant system and total entropy conservation → $T(\tau)/T_0 = (\tau/\tau_0)^{-c_s^2}$ with sound velocity : c_s^2

Mapping : 3D Ising⇔QCD



parameter setting

QGP creation: $T_0 = 220$ [MeV] ($\tau_0 = 1$ [fm]); critical point: $T_c = 160$ [MeV]; freeze-out: $T_f = 100$ [MeV]

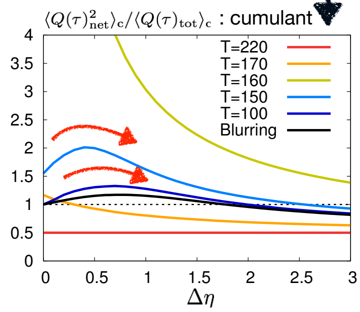
+Thermal blurring effect (coordinate-rapidity⇔momentum-rapidity) Ohnishi, et al., (2016)

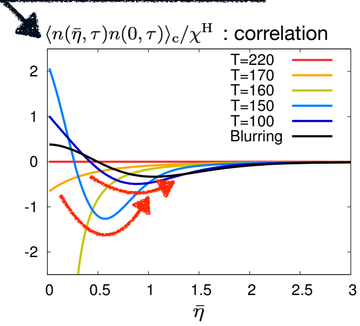
critical region: $\Delta T_c = 10$ [MeV]; proportional const. in the critical region: $l_c = 1.0$ [fm] $c_c = 4.0$

Thermal values in QGP and hadrons: $D^{\rm Q} = 2.0$ [fm] $D^{\rm H} = 0.6$ [fm] $\chi^{\rm Q}/\chi^{\rm H} = 0.5$; Sound velocity: $c_s^2 = 0.15$

6. Results

Time slice (temperature T[MeV]) of fluctuations when system pass on the critical point



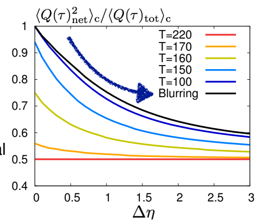


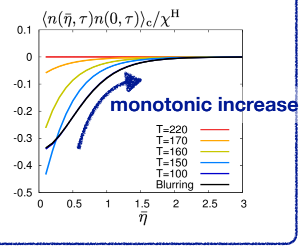
Non-monotonic behaviors = signal for the QCD critical point

For comparison, in the case of crossover transition

monotonic decrease

consistent with the experimental result at ALICE





7. Discussion

- The value of cumulant at $\Delta\eta = 0$ for a given T = Thermal value at the T

⇔ For $\Delta\eta \to \infty$, cumulant → the value at initial temperature $T_0 = 220$ [MeV]

$\Delta\eta$ dependence reflects time history of HIC!

- From analytic solutions,

Non-monotonicity in fluctuations ⇄ Peak in $\chi(\tau)$ = System pass near the critical point.

Non-monotonic behaviors are robust experimental signals!

8. Summary

- We studied time evolution of critical fluctuations of net-baryon.
- We employ a SDE in order to describe the diffusion property of the critical fluctuation.
- **Non-monotonic behaviors as functions of the rapidity interval are robust experimental signals for the QCD critical point!**