Poster Session 2 T07_1 #614

Space-time evolution of critical fluctuations in an expanding system

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QUARK MATTER KRAKÓW 2022

Introduction

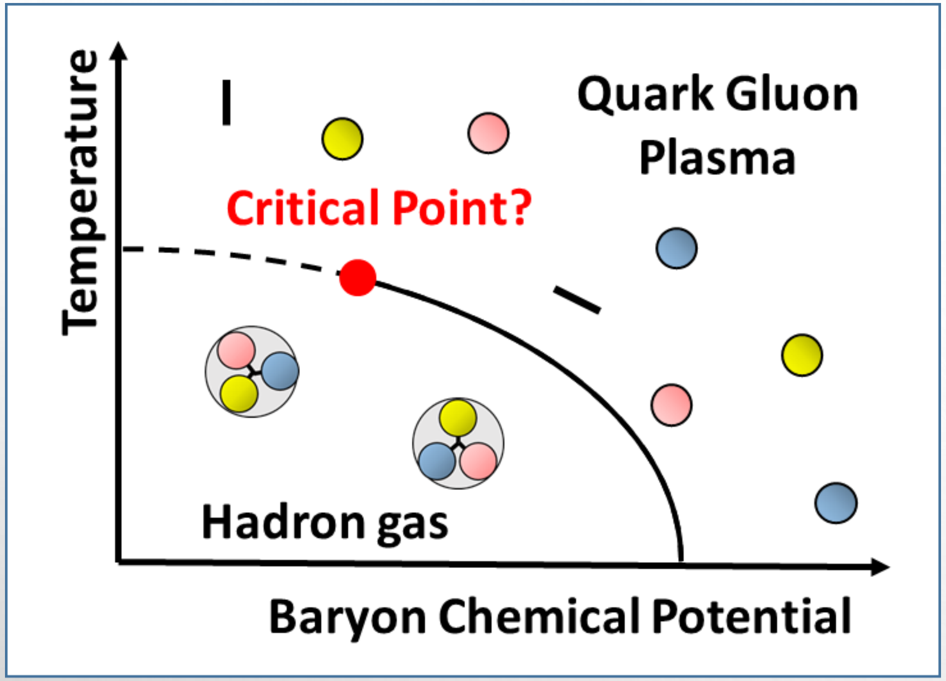


Fig. QCD Phase Diagram

Search for the QCD Critical Point

Dynamical modeling of heavy-ion collisions

Equilibrium: Infinite

Chiral condensate σ (Fast mode)→Ignored

Heavy-ion collisions: Finite

Time-scale separation is unclear

→ σ could affect the critical dynamics

Purpose of study:

We construct dynamical model of critical fluctuations

→ Coupling of Baryon number density n + Chiral condensate σ

→ Relaxation of baryon diffusion current from causality

Analyze the effects on correlation of baryon number density n

Model: coupled Langevin equations

$$\frac{d(\delta\sigma)}{dt} = -\Gamma\frac{\delta F}{\delta(\delta\sigma)} + \tilde{\lambda}\nabla^2\frac{\delta F}{\delta(\delta n)} + \xi_\sigma$$

$$\frac{\tau_R dV}{dt} + V = \tilde{\lambda}\nabla\frac{\delta F}{\delta(\delta\sigma)} + \lambda\nabla\frac{\delta F}{\delta(\delta n)} + \xi_n$$

$$\frac{d(\delta n)}{dt} = -\nabla\cdot V$$

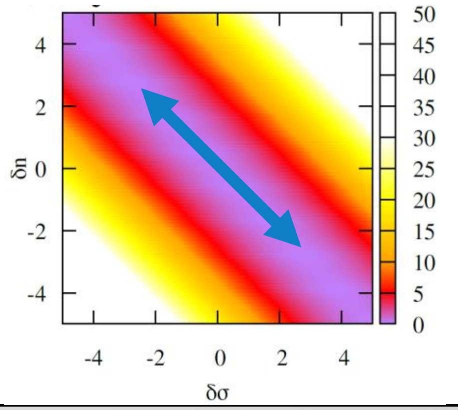
Critical fluctuations

Chiral condensate $\delta\sigma \equiv \bar{q}q - \langle\bar{q}q\rangle$

Baryon number density $\delta n \equiv \bar{q}\gamma_0 q - \langle\bar{q}\gamma_0 q\rangle$

Potential of free energy functional $F[\delta\sigma,\delta n]$

$$V(\delta\sigma,\delta n) = \frac{A}{2}\delta\sigma^2 + B\delta\sigma\delta n + \frac{C}{2}\delta n^2$$



Coupling term

Flat direction
$T_c = 160$ MeV

Fluctuation-dissipation relation

$$\langle\xi_i(x)\xi_j(x')\rangle = 2T\gamma_{ij}\delta^4(x-x')$$

$\Gamma, \tilde{\lambda}, \lambda$: Transport coefficient

T : Temperature

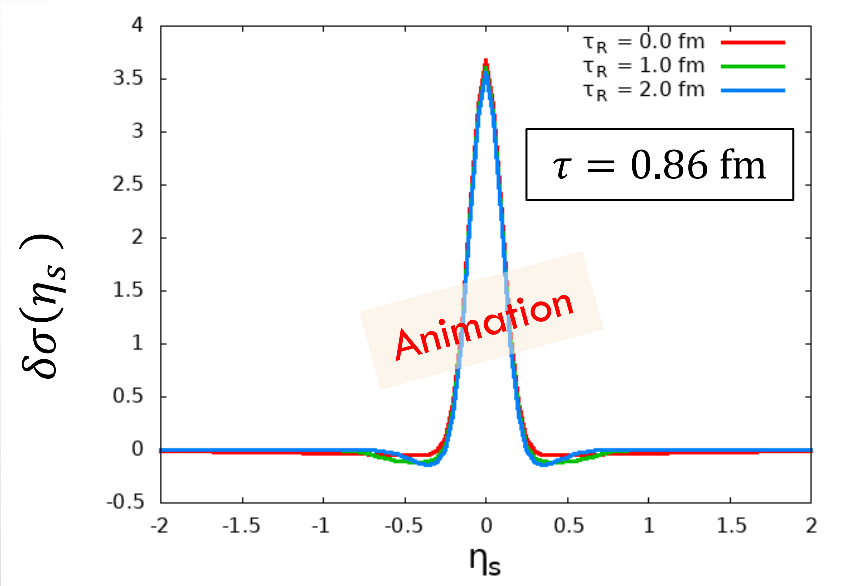
Diffusion equation violates causality

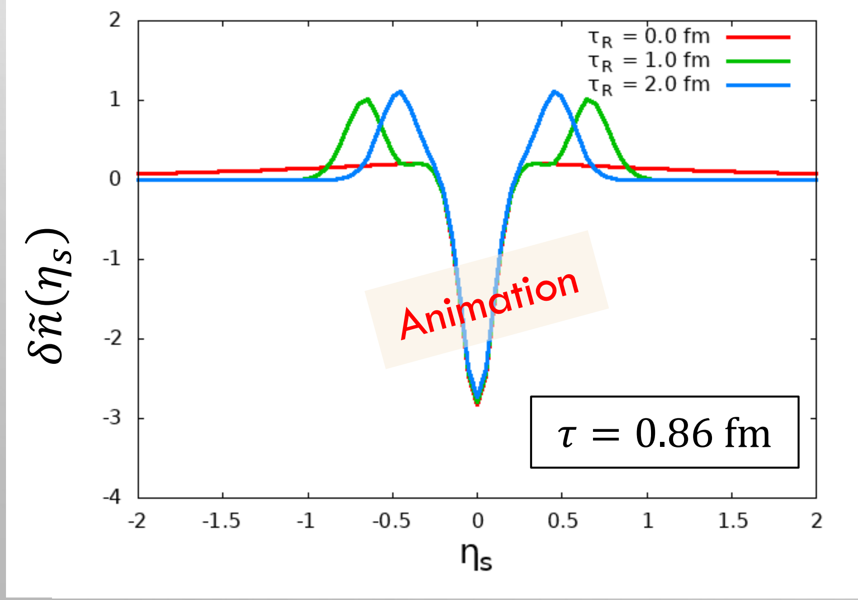
Introduce relaxation time τ_R
to make the propagation speed finite

New!

D.T. Son, M.A. Stephanov, Phys.Rev. D70 (2004) 056001
H. Fujii, M. Ohtani, Phys.Rev.D70:014016,2004

Results: Space-time evolution (1+1D)





Setups:

Temperature: $T(\tau) = T_0 \left(\frac{\tau_0}{\tau}\right)^{c_s^2}$

Initial temperature: $T_0 = 220\ \mathrm{MeV}$

Initial time: $\tau_0 = 0.6\ \mathrm{fm}$

Sound velocity: $c_s^2 = 0.15$

Critical temperature: $T_c = 160\ \mathrm{MeV}$

Without noise $\xi = 0$

Conserved quantity $\delta\tilde{n} \equiv \tau\delta n$

Initial conditions:

$$\delta\sigma(\eta_s, \tau_0) = \frac{1}{\sqrt{2\pi w^2}} e^{-\frac{\eta_s^2}{2w^2}}$$

$$\delta\tilde{n}(\eta_s, \tau_0) = 0$$

$\delta\tilde{n} \neq 0$ at $\tau > \tau_0$

$\rightarrow$ $\delta\sigma$ affects δn evolution in $\tau - \eta$ space (1+1D)

$\tau_R = 0$ fm: $\delta\tilde{n}$ instantly diffuse to large η_s

$\tau_R > 0$ fm: $\delta\tilde{n}$ diffuse at finite time

Signal propagates in a finite time
by considering relaxation time τ_R

Results: Correlation evolution vs τ_R

Correlation function:

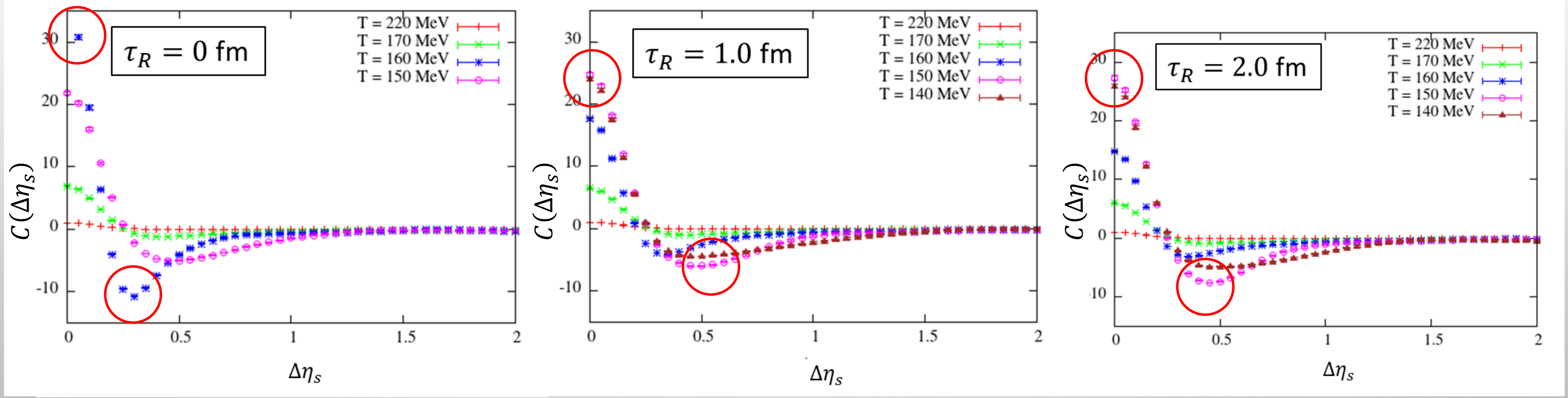
$$C(\Delta\eta_s) = \frac{\langle\delta\tilde{n}(\eta_s)\delta\tilde{n}(\eta_s+\Delta\eta_s)\rangle}{\langle\delta\tilde{n}(\eta_s)\delta\tilde{n}(\eta_s+\Delta\eta_s)\rangle_{T=220\ \mathrm{MeV},\Delta\eta_s=0}}$$

Setups:

$$\delta(\eta-\eta') \Rightarrow \frac{1}{\sqrt{2\pi w^2}} e^{-\frac{(\eta-\eta')^2}{2w^2}}$$ w: Gaussian width ($w = 0.1$)

Initial conditions:

$\delta\sigma(\eta_s,\tau_0) = 0$, Thermal equilibrium for $\delta\tilde{n}(\eta_s,\tau_0)$ $\quad B = 0$



Peak at $T_c = 160$ MeV — Peak between 150 MeV and 160 MeV — Peak around $T\sim150$ MeV

$C(\Delta\eta_s)$ at $\Delta\eta_s = 0$ reaches its peak value earlier for $\tau_R = 0$ fm than $\tau_R = 1, 2$ fm cases

Finite relaxation time τ_R causes a delay of response

Summary and Outlook

◆**We constructed a second-order model for critical fluctuations in 1+1D and analyzed the space-time evolution and correlation evolution**

- Coupled Baryon density δn and Chiral condensate $\delta\sigma$
- Introduced relaxation time τ_R

◆ **Space-time evolution of $\delta\sigma$ and δn**

- $\delta\sigma$ distribution affects δn distribution
- Signal propagates in a finite time by considering relaxation time τ_R

◆ **Correlation evolution vs τ_R**

- Peak at $\Delta\eta_s\sim 0$
- Finite relaxation time τ_R causes a delay of response

◆**Outlook**

- Analyze the effect on observables