Time evolution of conserved-charge fluctuations near the QCD critical point

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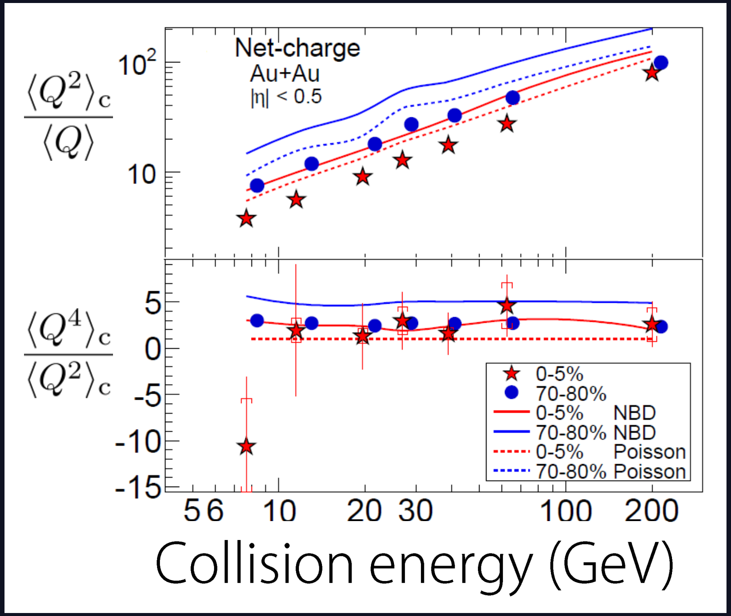
Fluctuation signature for QCD CP

Near CEP, $\langle Q^2 \rangle_c^{eq} \sim \xi_{eq}^2 \to \infty$

$\langle Q^{3 \text{ or } 4} \rangle_c^{eq} \sim \xi_{eq}^{4.5 \text{ or } 7} \to \infty$ + sign change

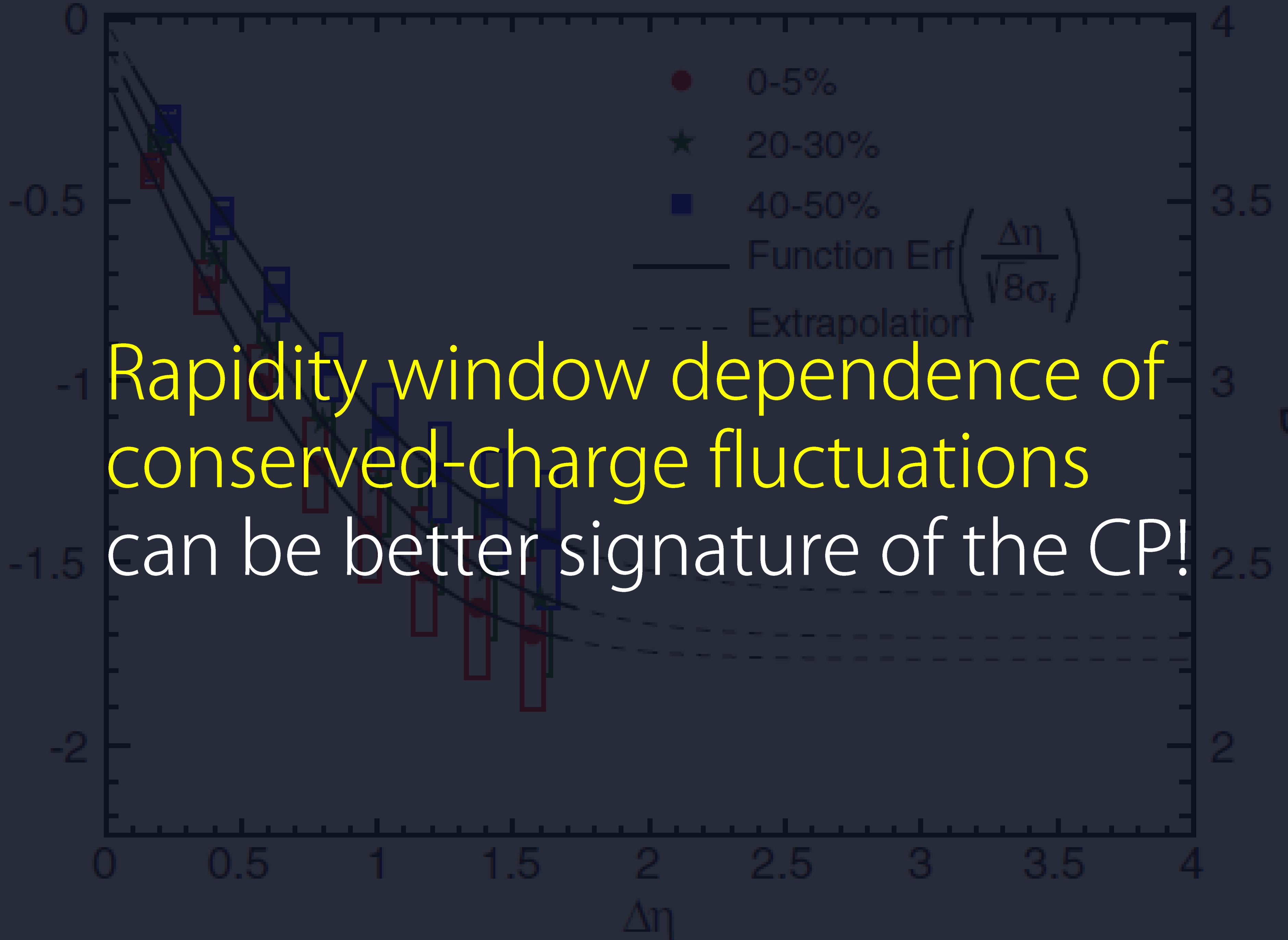
Asakawa et. al., PRL103,262301 (09), Stephanov, PRL102, 032301 (09)

singular behavior = signature!!



STAR, PRL113, 092301 (2014)

⚠ But due to critical slowing down & final state interactions, catching such signals is not so easy…



Rapidity window dependence of
conserved-charge fluctuations
can be better signature of the CP!

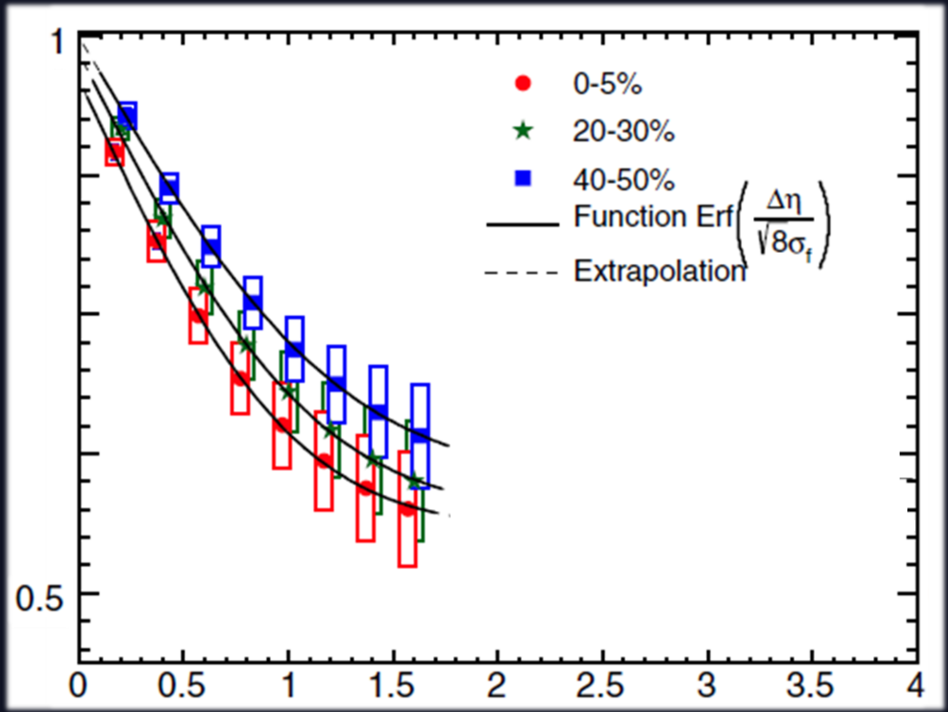
$\Delta\eta$ dependence of charge fluctuation

Variance of net electric charge

$$\frac{\langle N_{\mathrm{Q}}^{(\mathrm{net})2}\rangle_{\mathrm{c}}}{\langle N_{\mathrm{Q}}^{+} + N_{\mathrm{Q}}^{-}\rangle_{\mathrm{c}}}$$

Asakawa, Heinz, Muller (2000)
Jeon, Koch (2000)

ALICE, PRL**110**, 152301 (2013)



$\Delta\eta$: rapidity window

$\Delta\eta$ dependence of charge fluctuation

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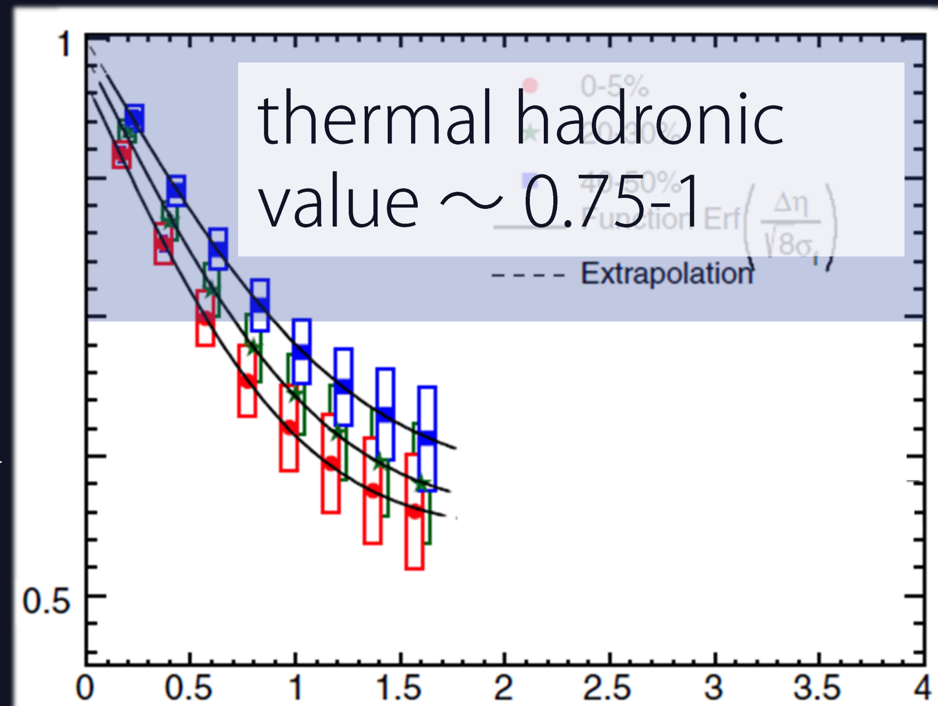

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$\Delta\eta$ dependence of charge fluctuation

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$$\frac{\langle N_Q^{(\mathrm{net})2} \rangle_c}{\langle N_Q^+ + N_Q^- \rangle_c}$$

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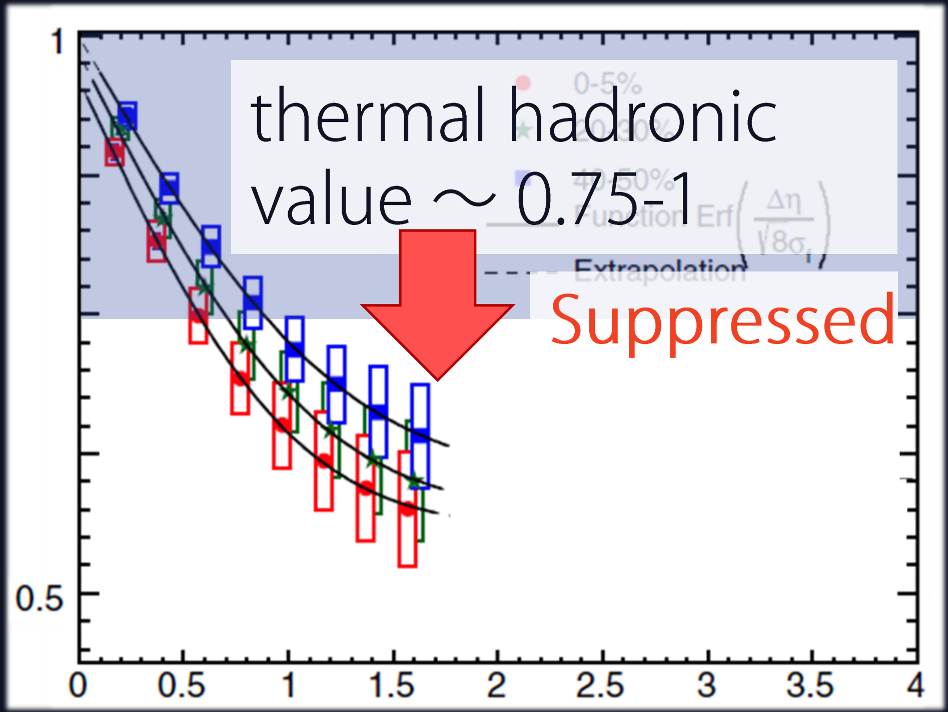
ALICE, PRL**110**, 152301 (2013)



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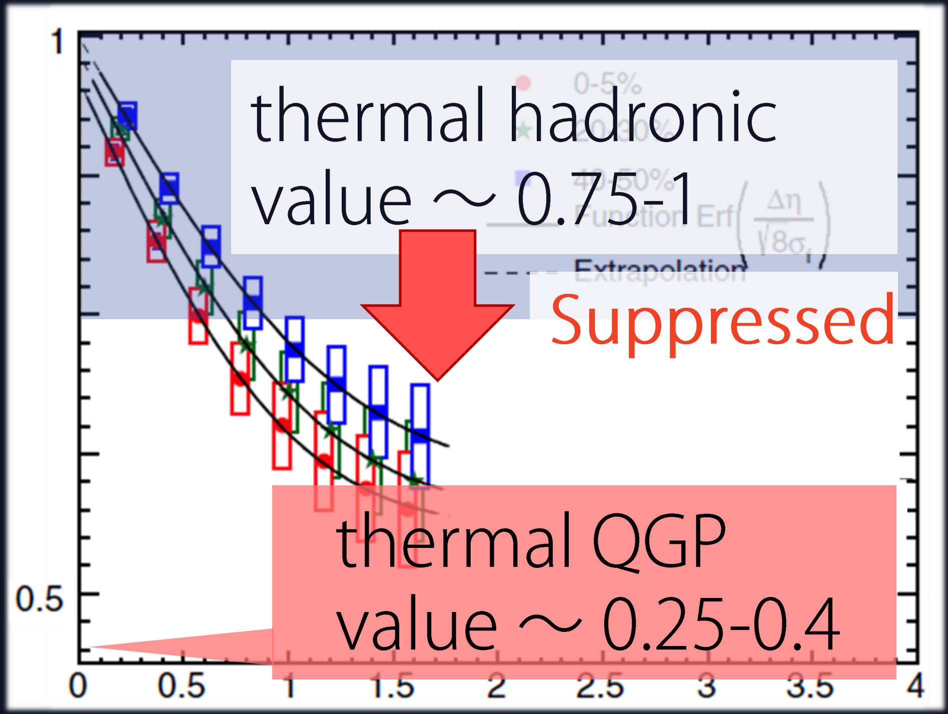

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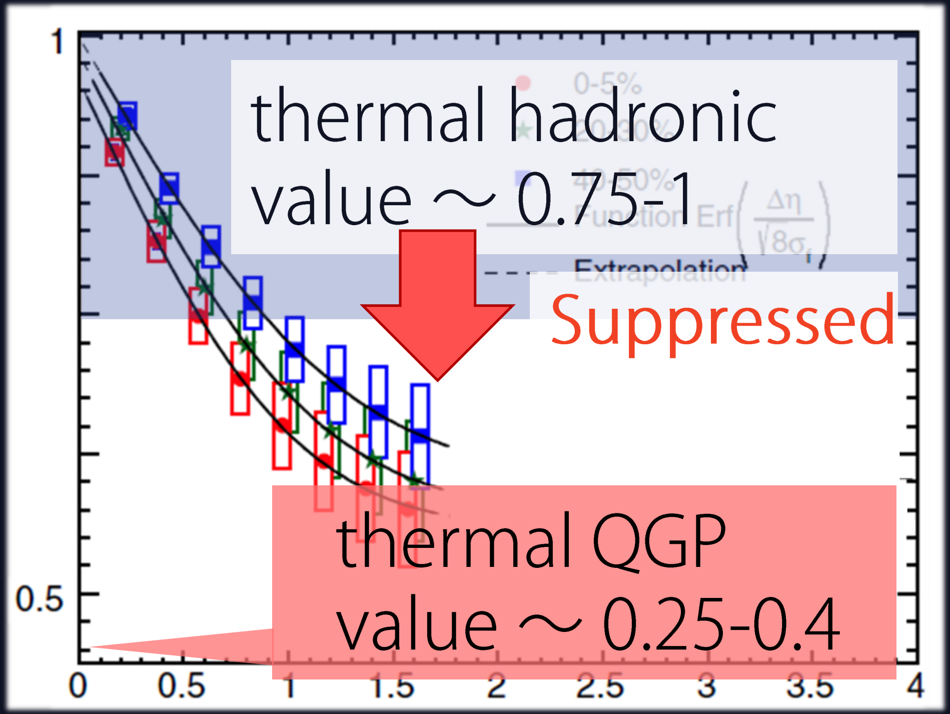
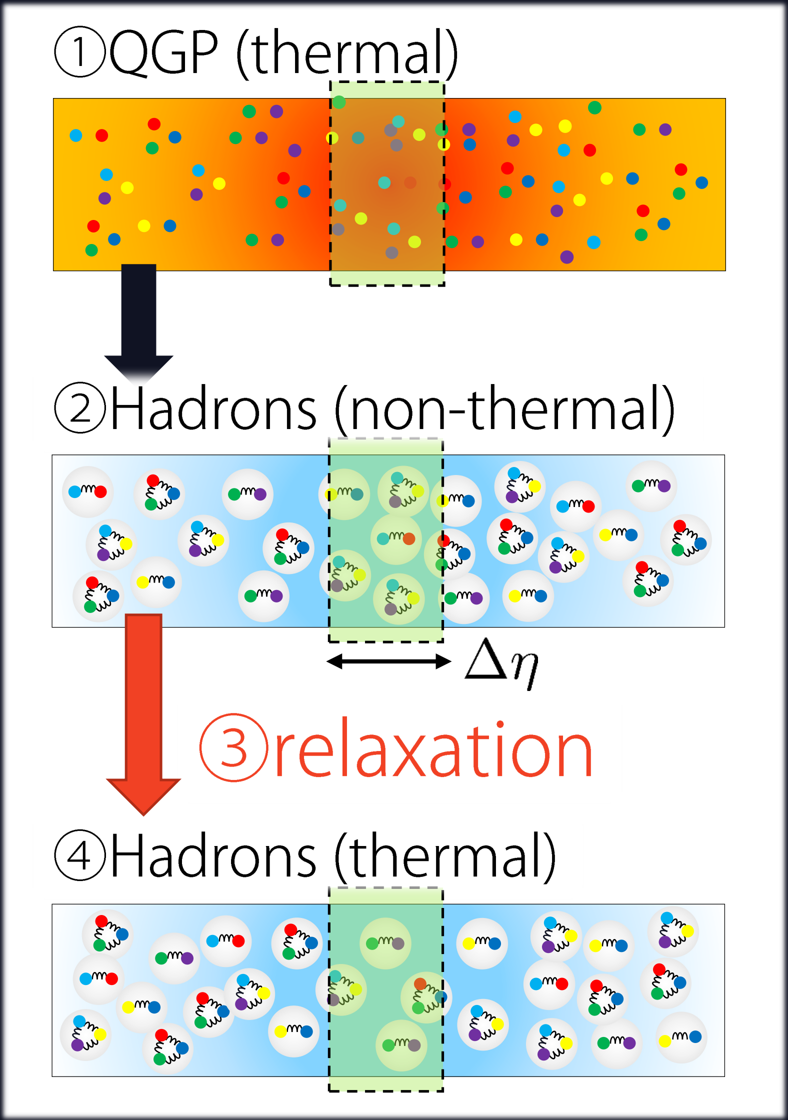
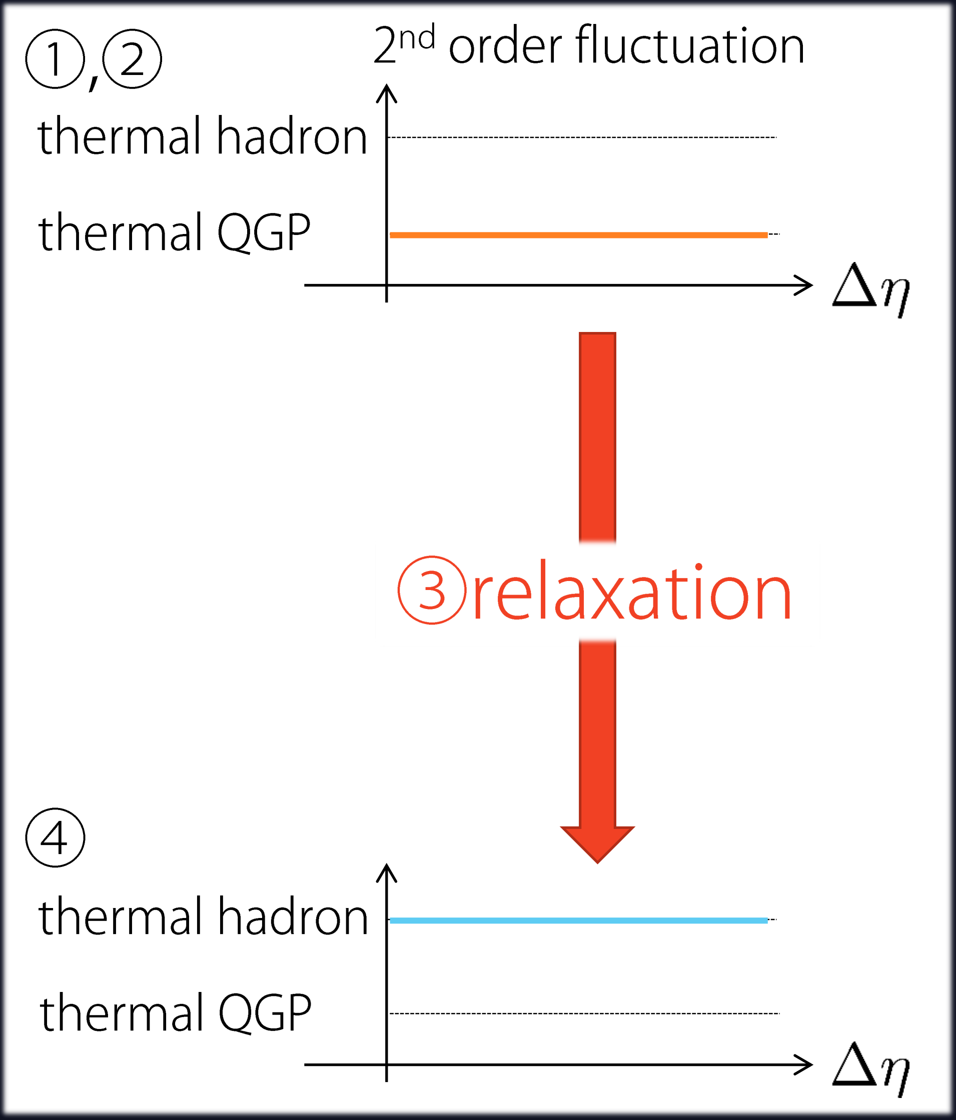


$\Delta\eta$: rapidity window

Fluctuations for larger $\Delta\eta$ are not thermal at kinetic freeze-out (?)

Time evolution of fluctuations





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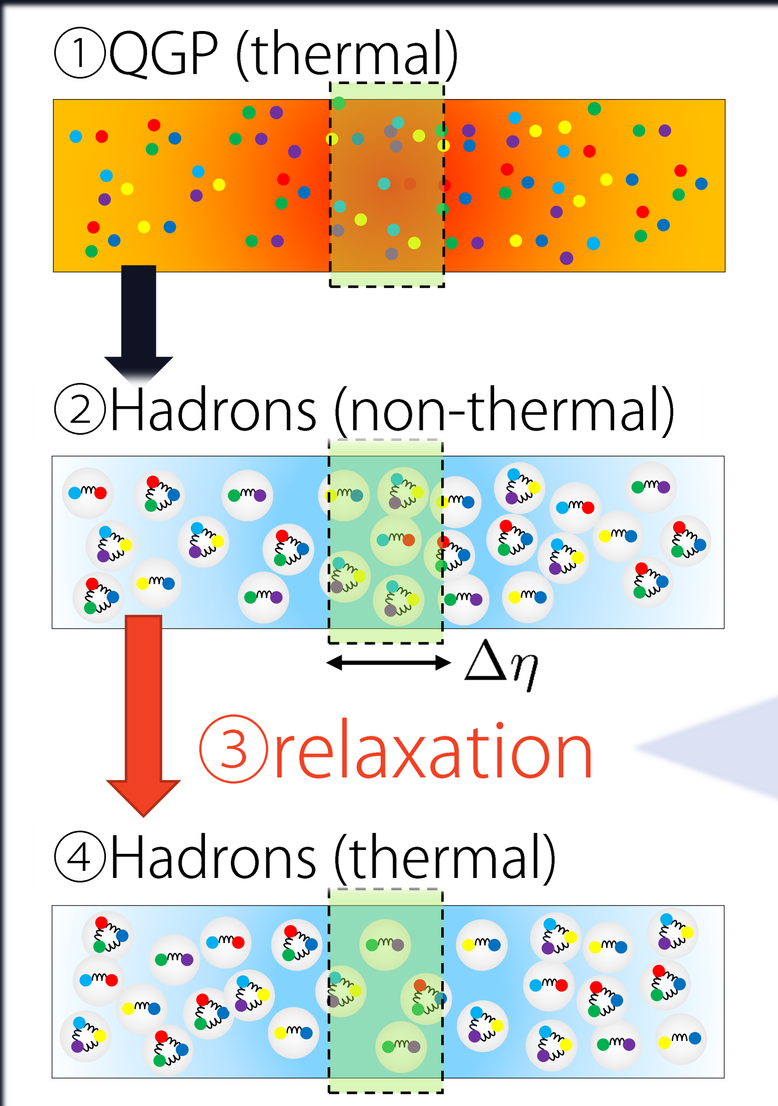
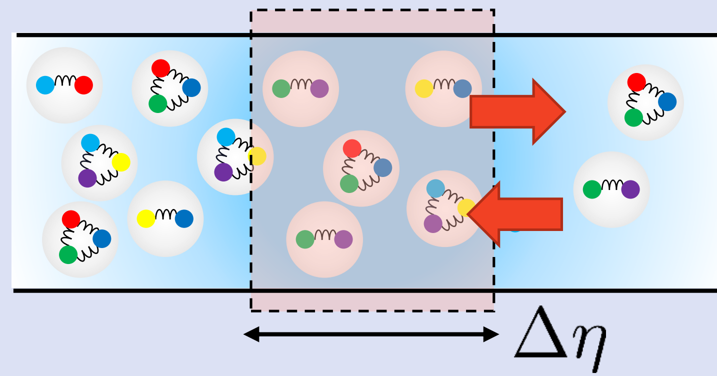


Relaxation can only proceed by charge diffusion!!

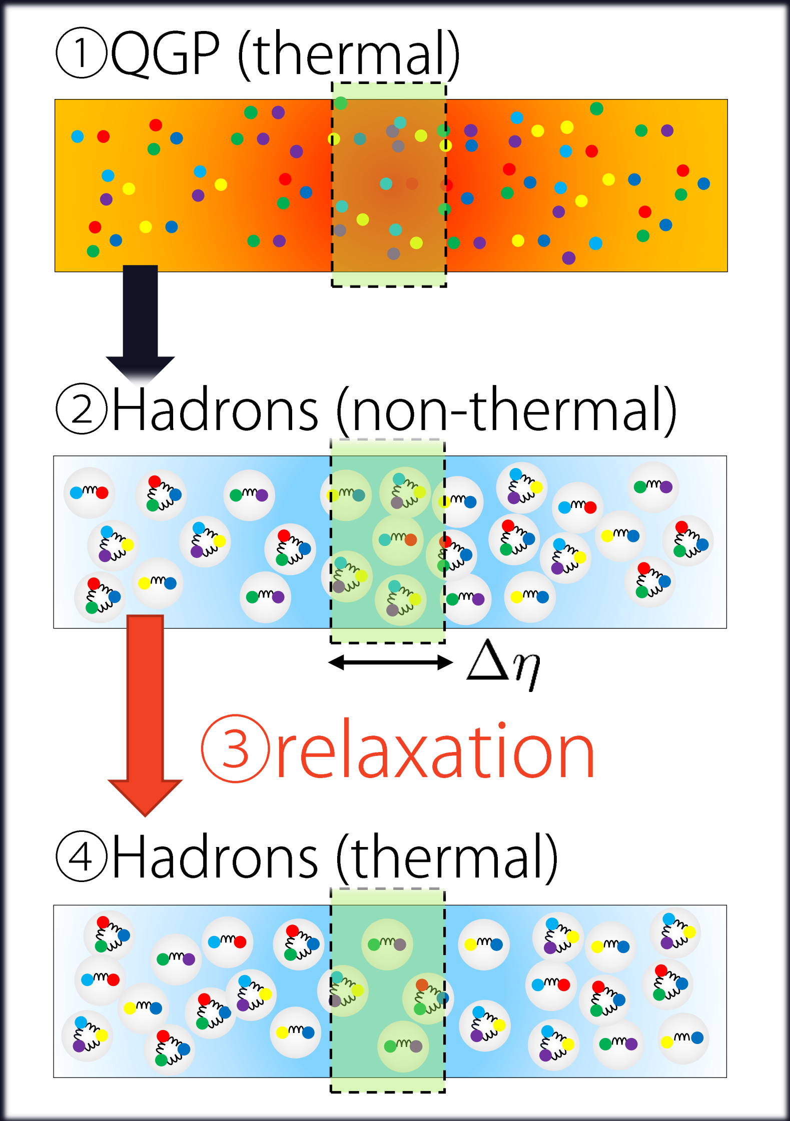
Shuryak, Stephanov (2001)

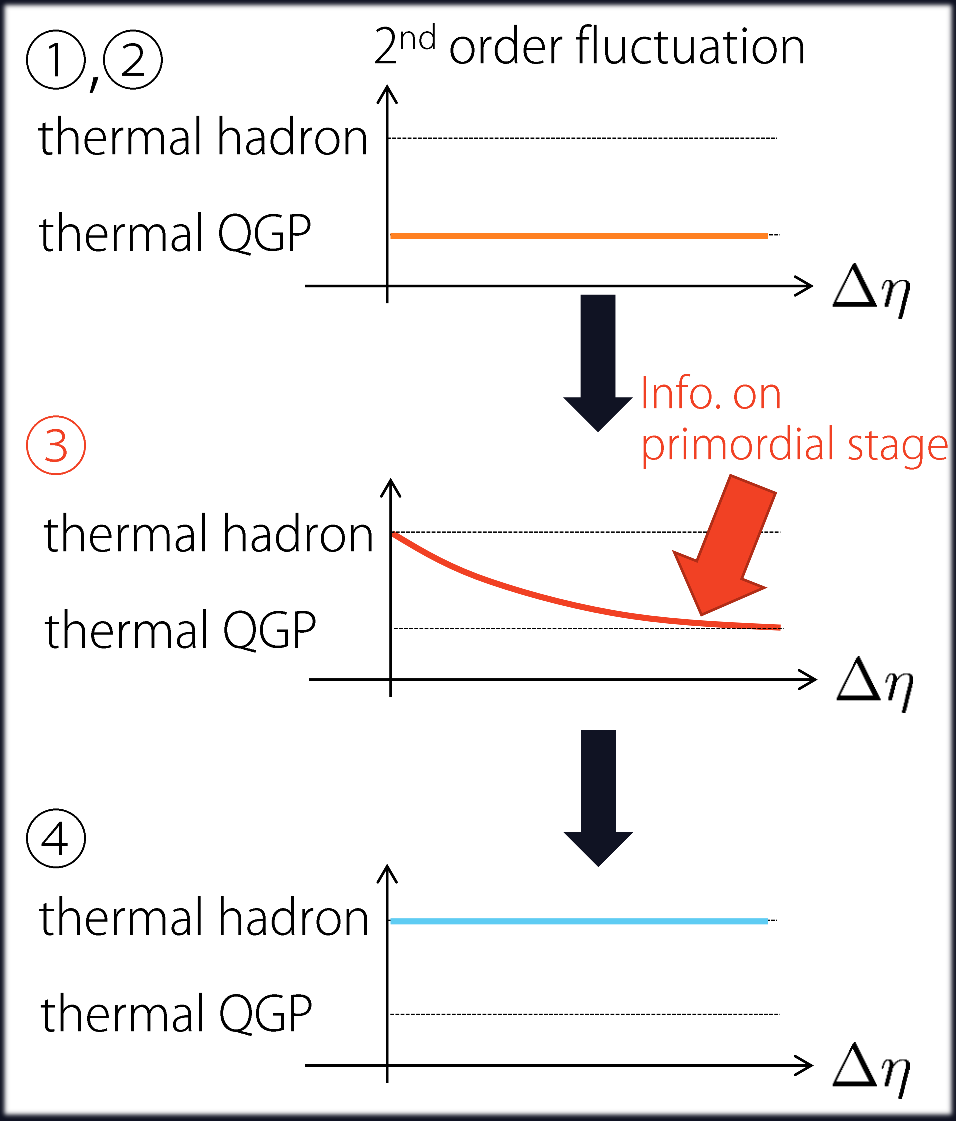


$\Delta\eta \rightarrow$ larger

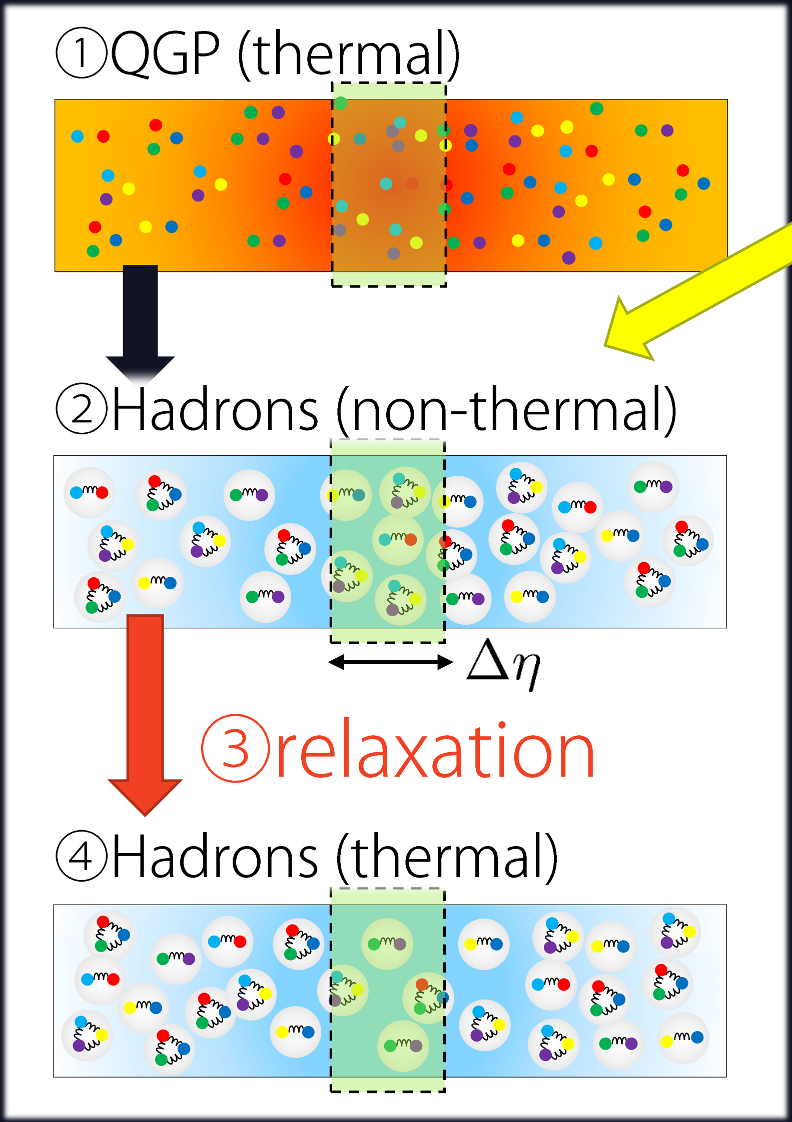
relaxation time→longer (more QGP value)

Time evolution of fluctuations

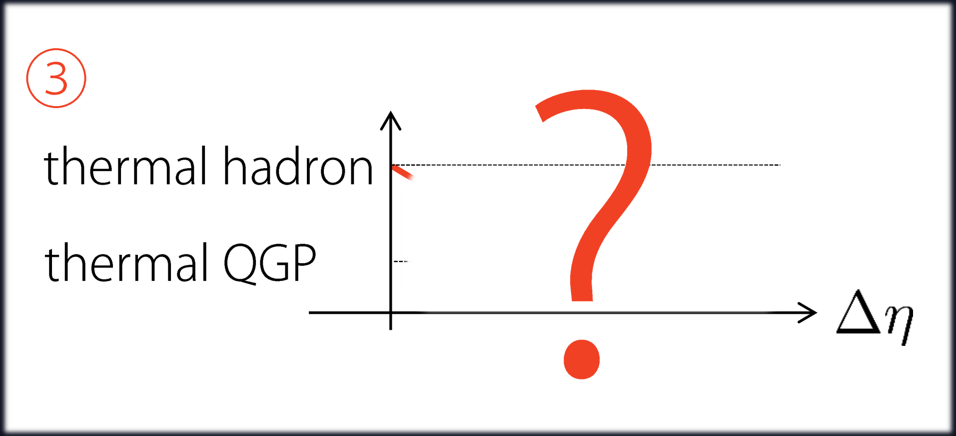




Time evolution of fluctuations



If system passes near the CP,



criticality should appear for larger $\Delta\eta$!!

Time evolution of fluc. near the CP

Q. How to describe time evolution of CC fluc. near the CP?

- Previous study on dynamical critical fluc.

  Berdnikov, Rajagopal (2000), Nonaka, Asakawa (2005), Mukherjee et. al. (2015)

☹do not take into account the conservation effect

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↕

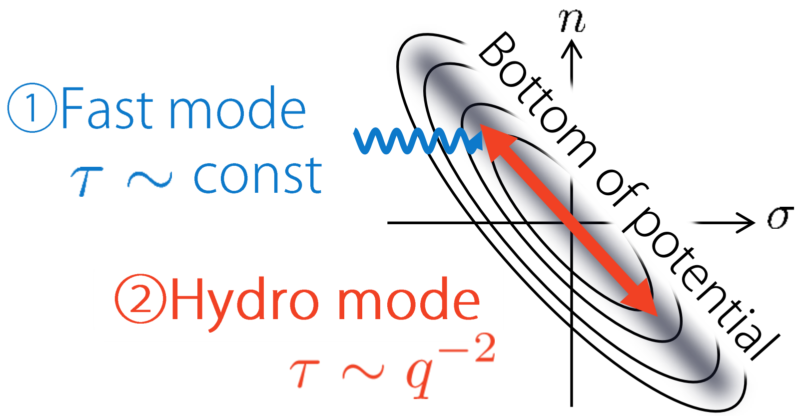
At QCD CP, n and σ are coupled
→ critical fluctuation is hydrodynamic mode

Fujii, Ohtani, PRD70, 014016 (2004), Son, Stephanov, PRD70, 056001(2004)

→ We must take into account the conservation effect in order to discuss dynamical CC fluc. near CP.

How to describe?

- Near the QCD CP → Stochastic diffusion eq. (SDE)



Fujii, Ohtani, PRD70, 014016 (2004)
Son, Stephanov, PRD70, 056001(2004)

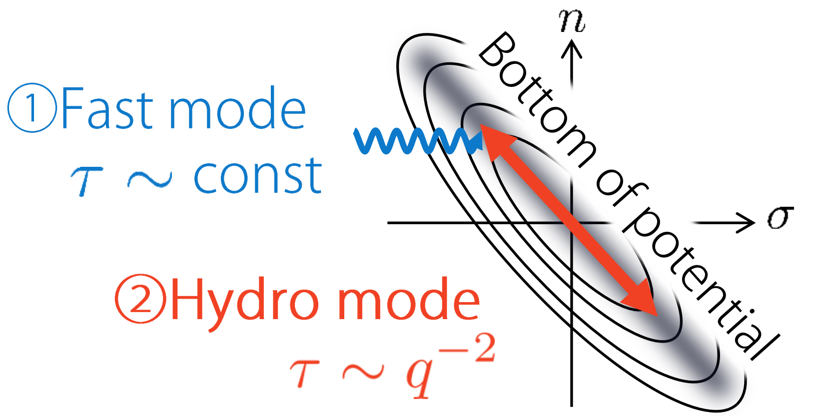
At longer time scale,
σ can be forgotten.

n relaxes solely
with diffusive time scale.

$$\frac{\partial}{\partial \tau} n = D \frac{\partial^2}{\partial \eta^2} n + \frac{\partial}{\partial \eta} \xi$$

How to describe?

- Near the QCD CP → Stochastic diffusion eq. (SDE)



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At longer time scale, σ can be forgotten.

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$$\frac{\partial}{\partial \tau} n = D \frac{\partial^2}{\partial \eta^2} n + \frac{\partial}{\partial \eta} \xi$$

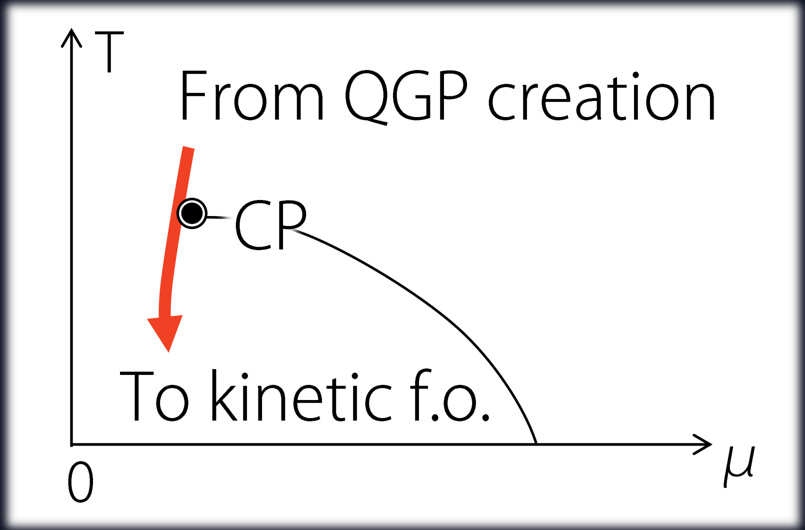
- Non-critical region → also SDE

Shuryak, Stephanov (2001), Kitazawa, Asakawa, Ono (2013), MS, Asakawa, Kitazawa (2014)

We can use SDE uniformly at all stage !

Our Strategy

Stochastic diffusion eq. $$\frac{\partial}{\partial\tau}n = D\frac{\partial^2}{\partial\eta^2}n + \frac{\partial}{\partial\eta}\xi$$



Solve(assumption: white noise)

$\Delta\eta$ dependence of conserved charge fluc.

Our Strategy

Stochastic diffusion eq. $\frac{\partial}{\partial \tau} n = D \frac{\partial^2}{\partial \eta^2} n + \frac{\partial}{\partial \eta} \xi$

- **Near the QCD CP**
  - Dynamical universality class → model H

    susceptibility $\chi_B \sim \xi^2$, Diffusion coefficient $D \sim \xi^{-1}$

    Hohenberg, Halperin, Rev. Mod. Phys. 49, 435 (1977)
  - 3D Ising mapping
- **Non-critical region**
  - $\chi_B^{\mathrm{hadron}} = 1, \chi_B^{\mathrm{QGP}} = 0, D = \mathrm{const}$

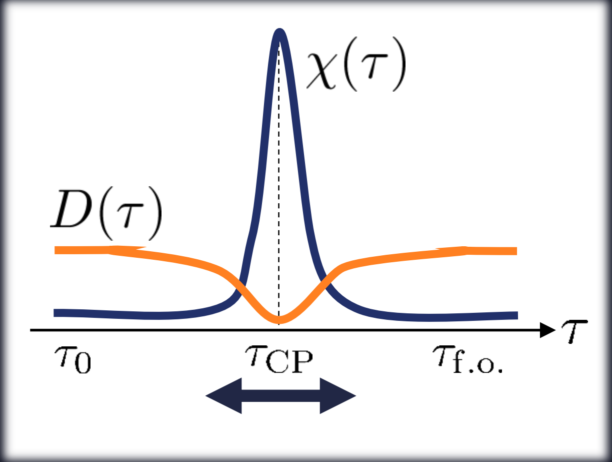
Solve(assumption: white noise)

$\Delta\eta$ dependence of conserved charge fluc.

Discussion of obtained formula

$$\langle n(q_1,\tau)n(q_2,\tau)\rangle_c = 4\pi q_1^2 \delta(q_1+q_2)\int_{\tau_0}^{\tau} d\tau' \chi_B(\tau')D(\tau')\exp\left[-2q_1^2\int_{\tau'}^{\tau} d\tau'' D(\tau'')\right]$$

World of τ



D → 0 = critical slowing down

Discussion of obtained formula

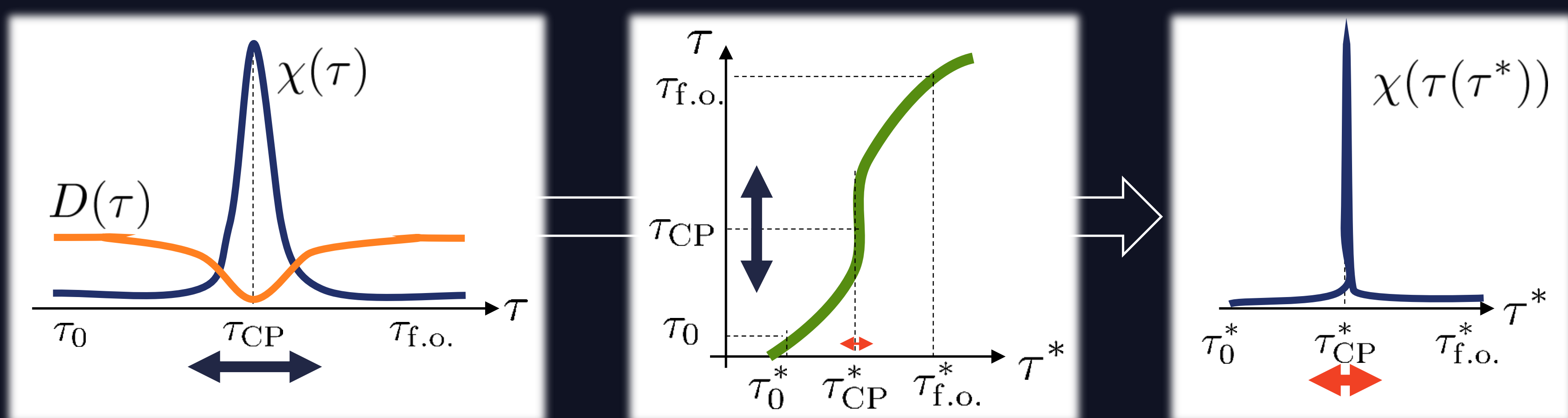
$$\langle n(q_1,\tau)n(q_2,\tau)\rangle_c = 4\pi q_1^2\delta(q_1+q_2)\int_{\tau_0}^{\tau} d\tau'\chi_B(\tau')D(\tau')\exp\left[-2q_1^2\int_{\tau'}^{\tau} d\tau'' D(\tau'')\right]$$

Transform as

$$d\tau^* = d\tau D(\tau)$$

$$\Rightarrow 4\pi q_1^2\delta(q_1+q_2)\int_{\tau_0^*}^{\tau^*} d\tau'^*\chi_B(\tau'(\tau'^*))\exp\left[-2q_1^2(\tau^*-\tau'^*)\right]$$

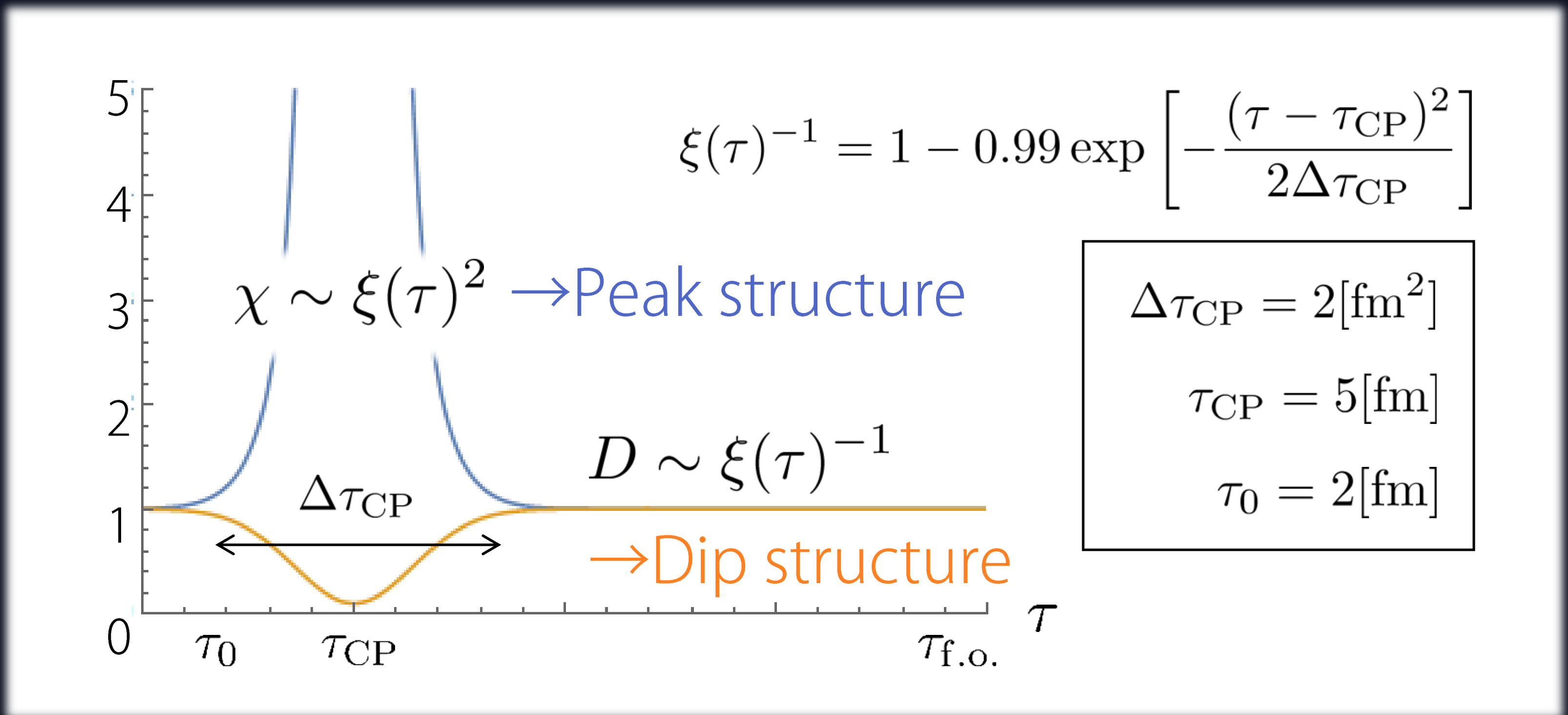
World of τ | Transform $\tau \rightarrow \tau^*$ | World of τ^*



Time scale is compressed near CP = critical slowing down

Our Strategy (Simple case)

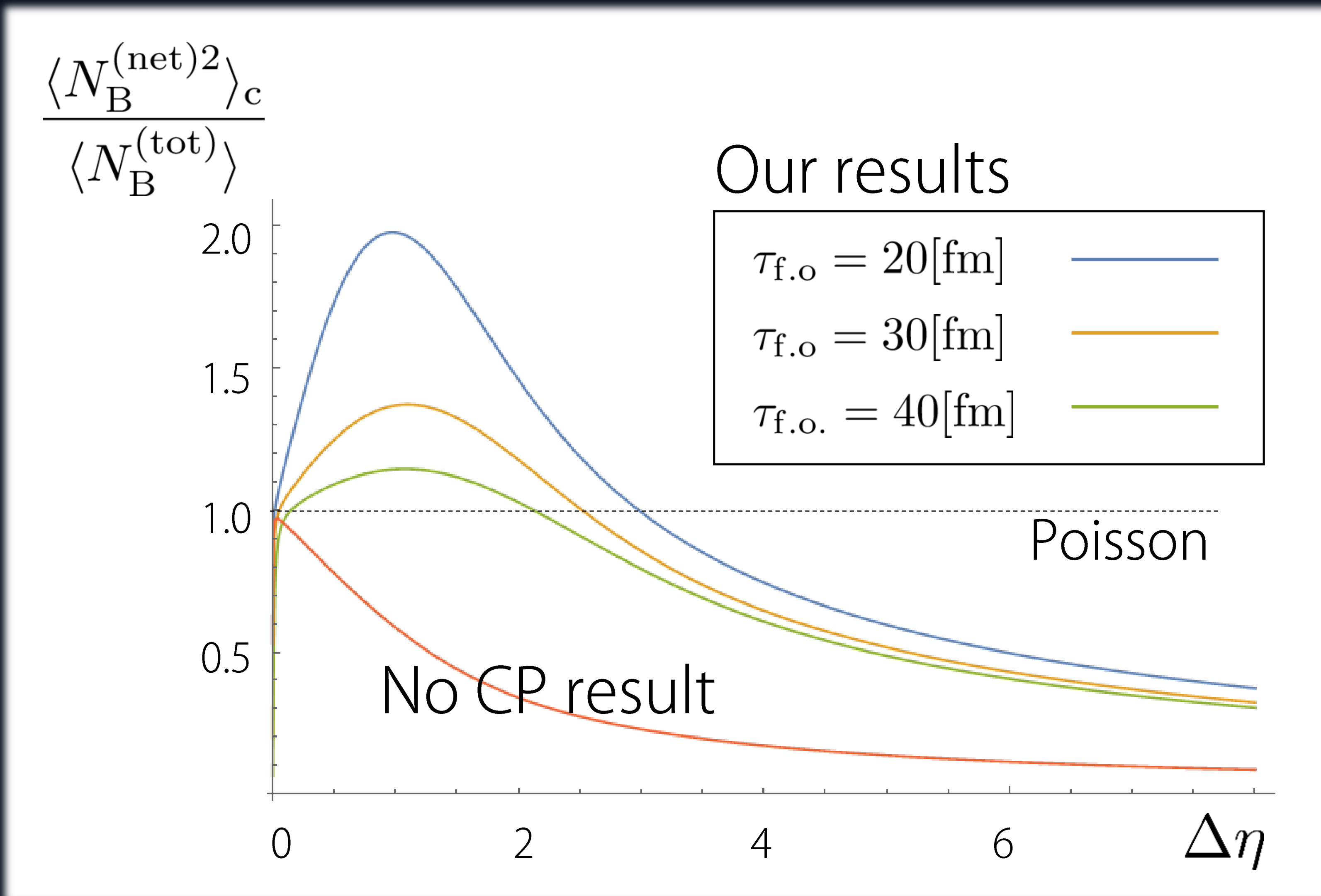
Stochastic diffusion eq. $$\frac{\partial}{\partial\tau}n = D\frac{\partial^2}{\partial\eta^2}n + \frac{\partial}{\partial\eta}\xi$$



Solve(assumption: white noise)

$\Delta\eta$ dependence of conserved charge fluc.

Result on $\Delta\eta$ dep. of CC fluctuations



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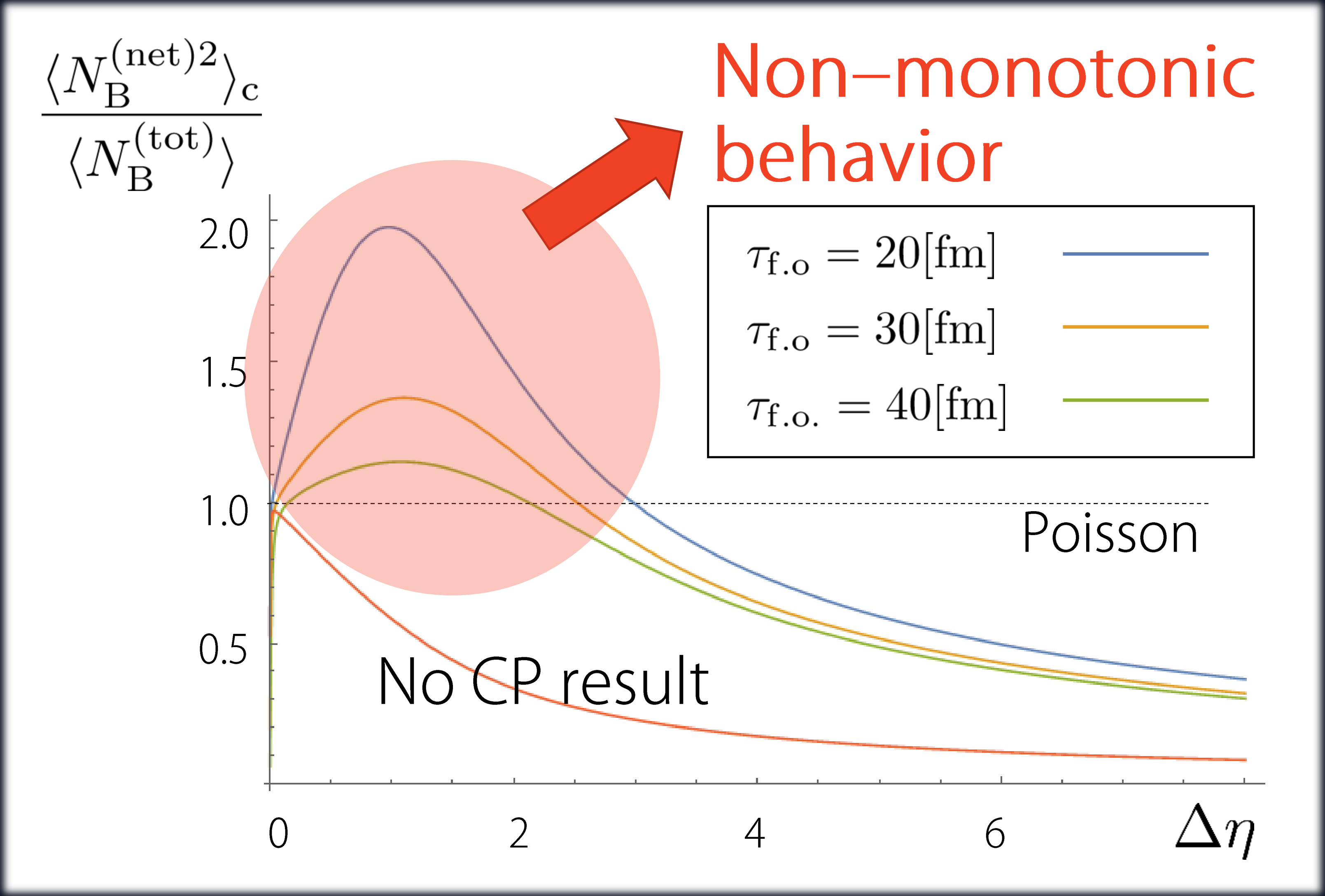

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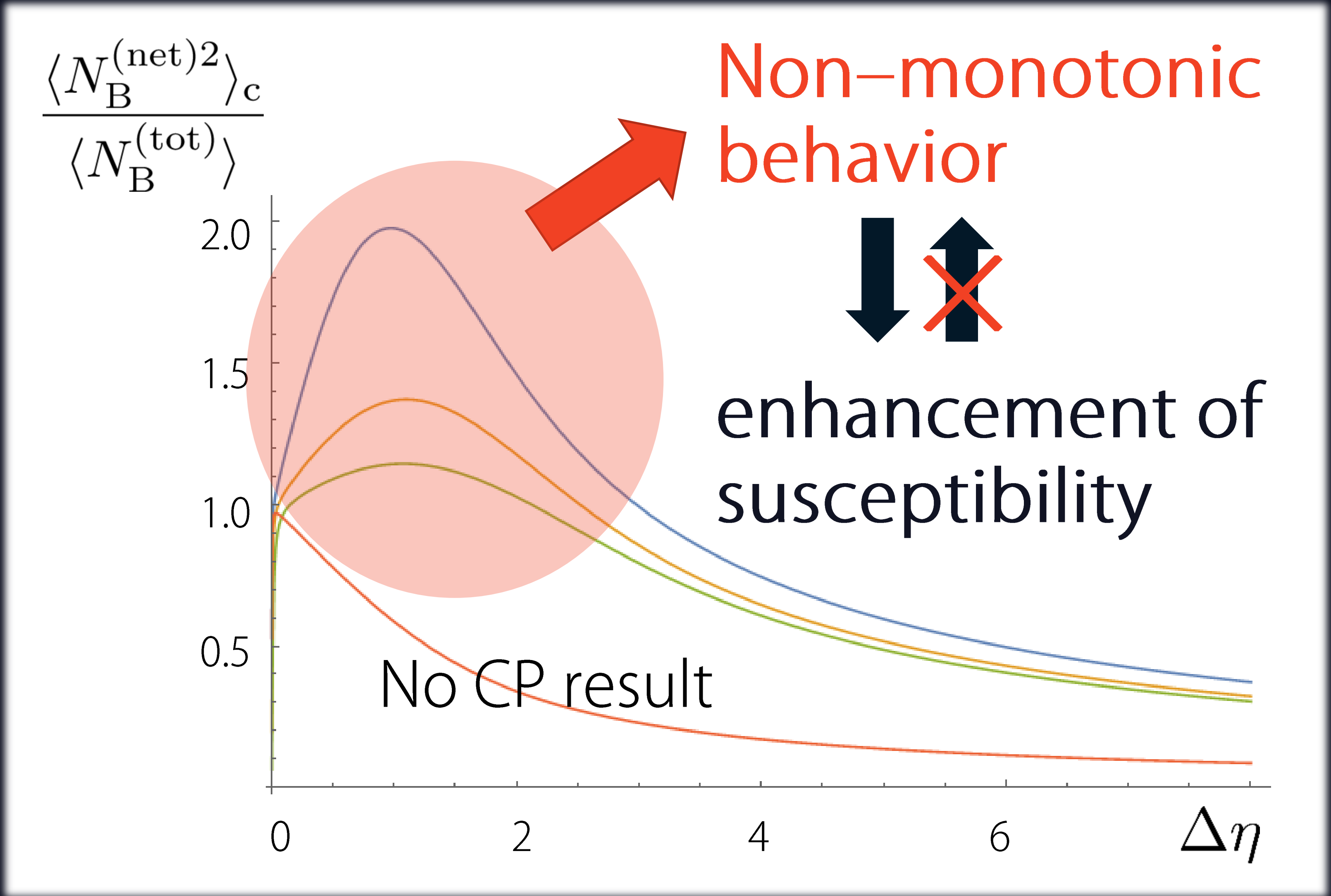

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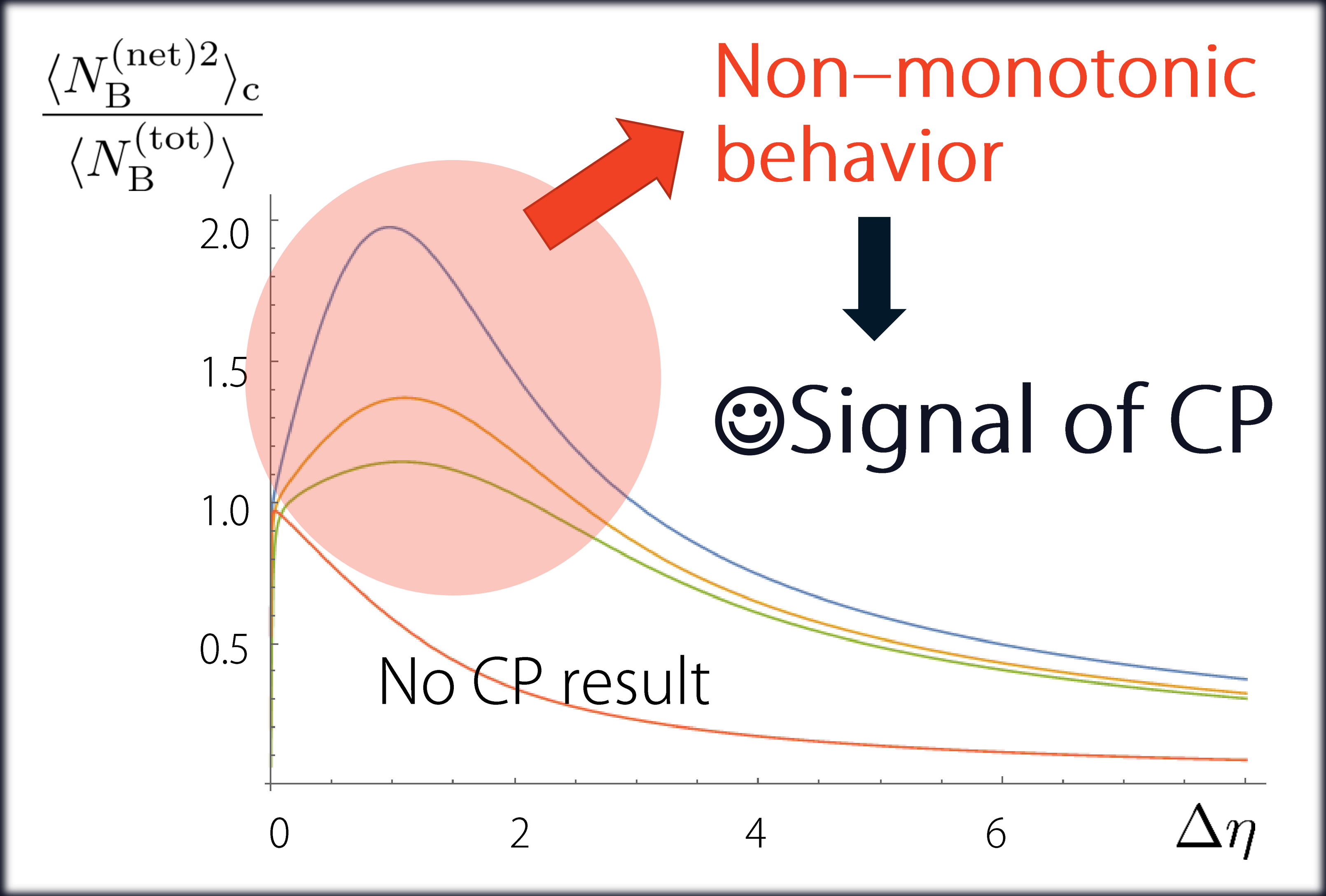

Summary

We study the time evolution of CC fluctuations in the case that system pass near the CP.

- We use SDE from QGP creation to kinetic freeze out.
- If system passes near the CP,
  $\Delta\eta$ dep. of fluc. may show non-monotonic behavior.

  →If the non-monotonic behavior can be observed in experiment, it is a signal of CP !!

$\Delta\eta$ dependence of CC fluctuations can be better signature of the CP!