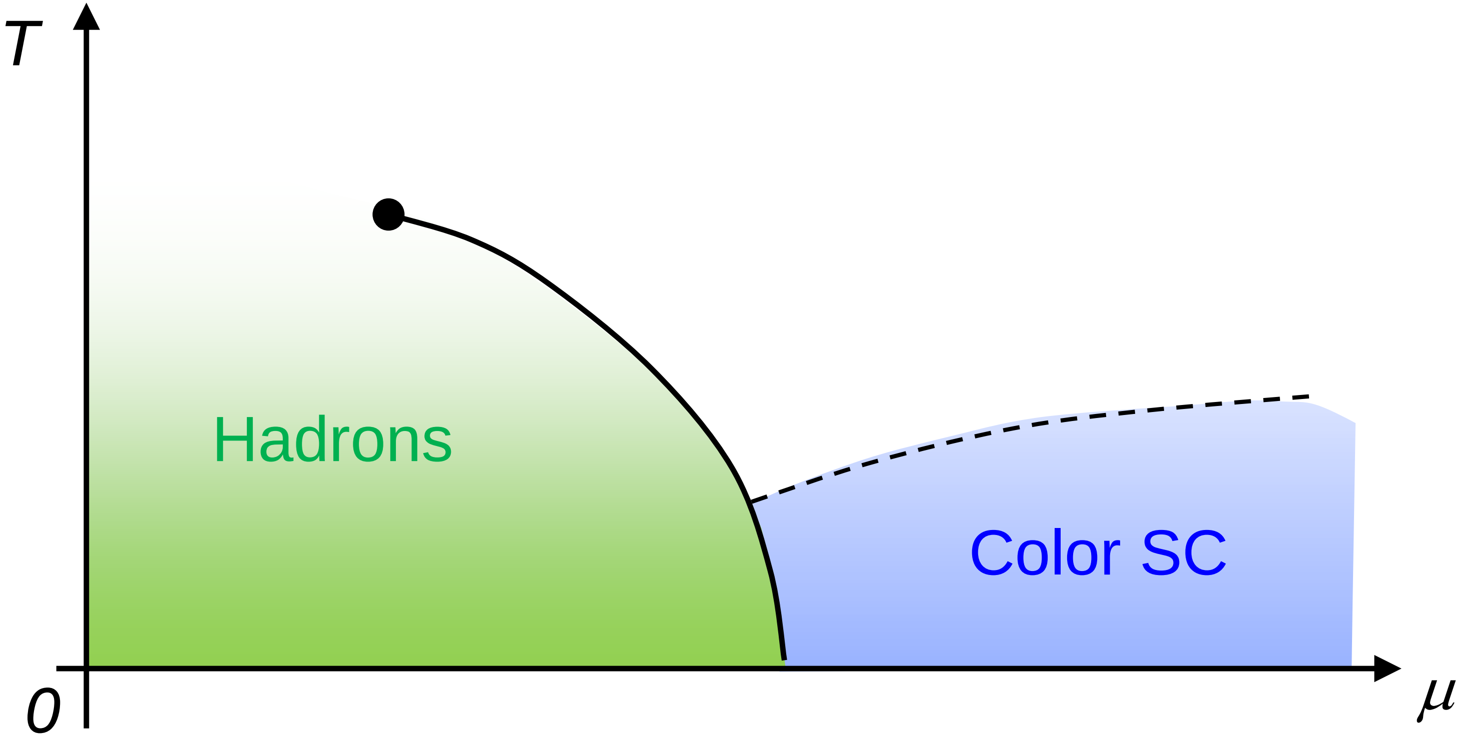
Diffusion of non-Gaussian fluctuations of conserved charges

Masakiyo Kitazawa
(Osaka U.)

MK, Asakawa, Ono, Phys. Lett. B728 (2014) 386-392;
MK, Nucl. Phys. A942 (2015) 65-96;
Y. Ohnishi et al., in prep.

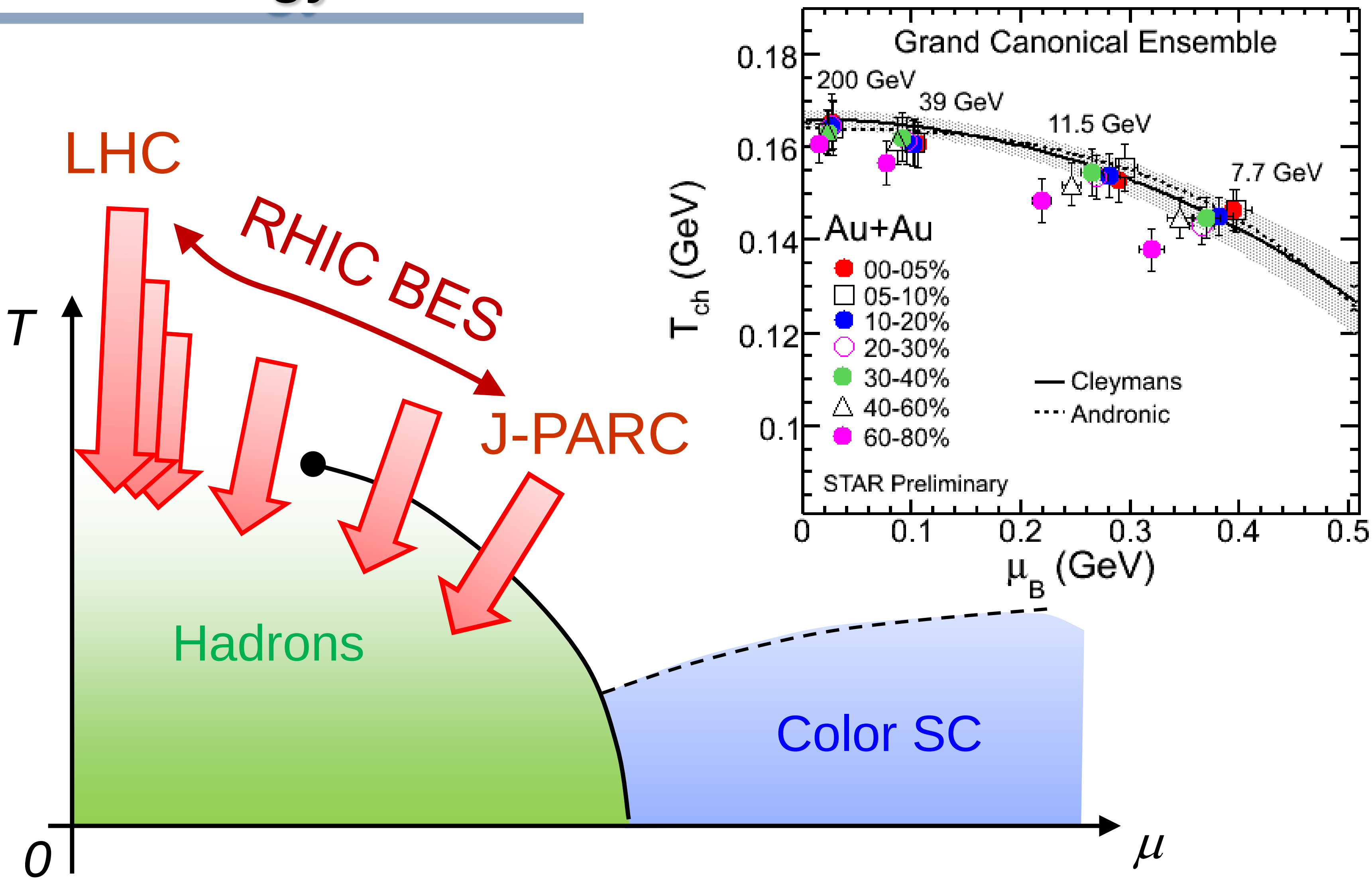
『熱場の量子論』, YITP, 2015/9/1

Beam-Energy Scan

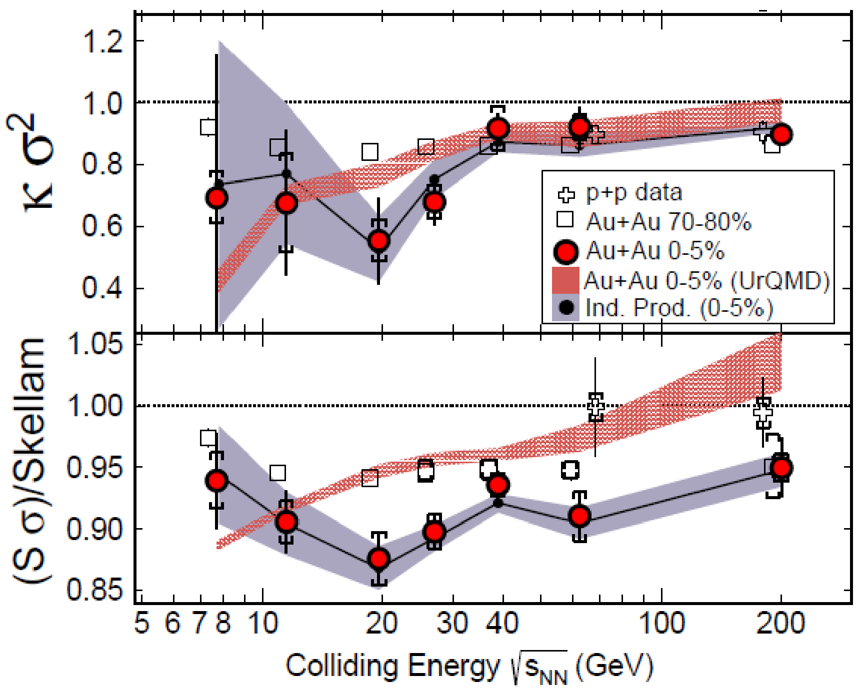


Beam-Energy Scan

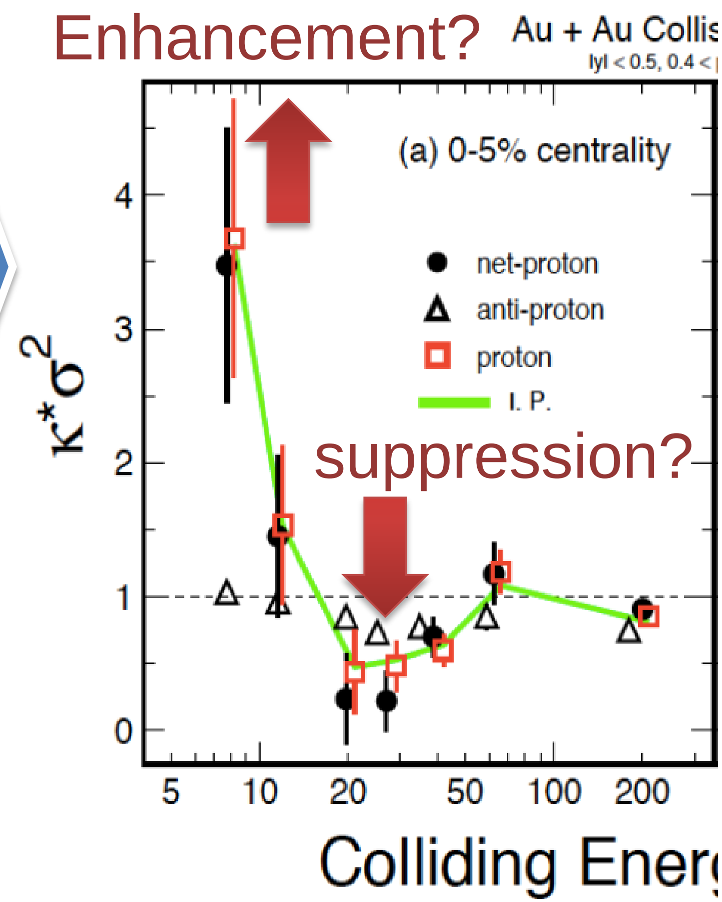
STAR 2012



Non-Gaussian Cumulants @ BES



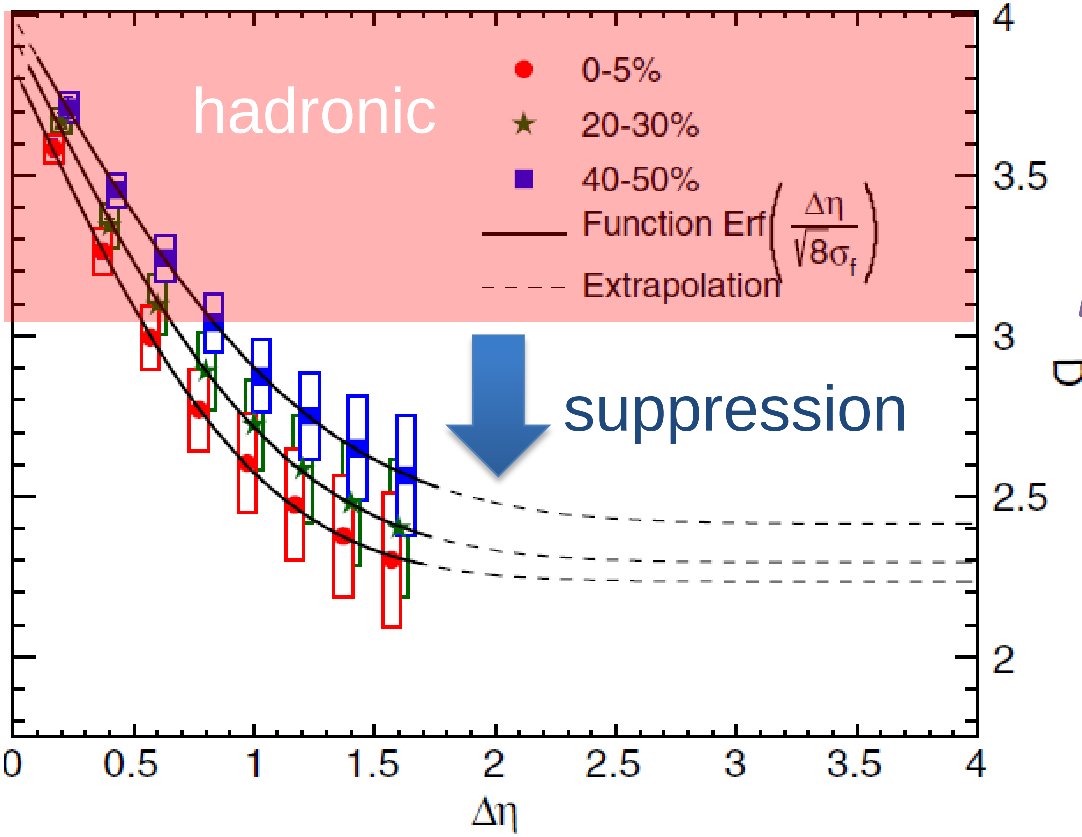
STAR, PRL (early 2014)



STAR, CPOD (Nov., 2014)

Δη Dependence @ ALICE

ALICE
PRL 2013

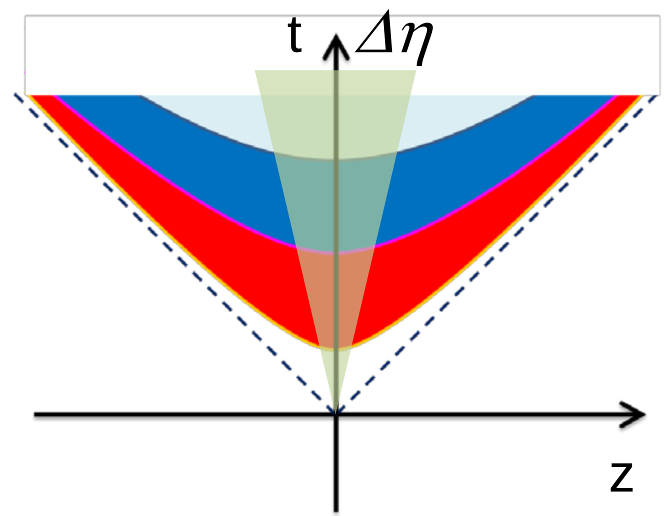


rapidity window

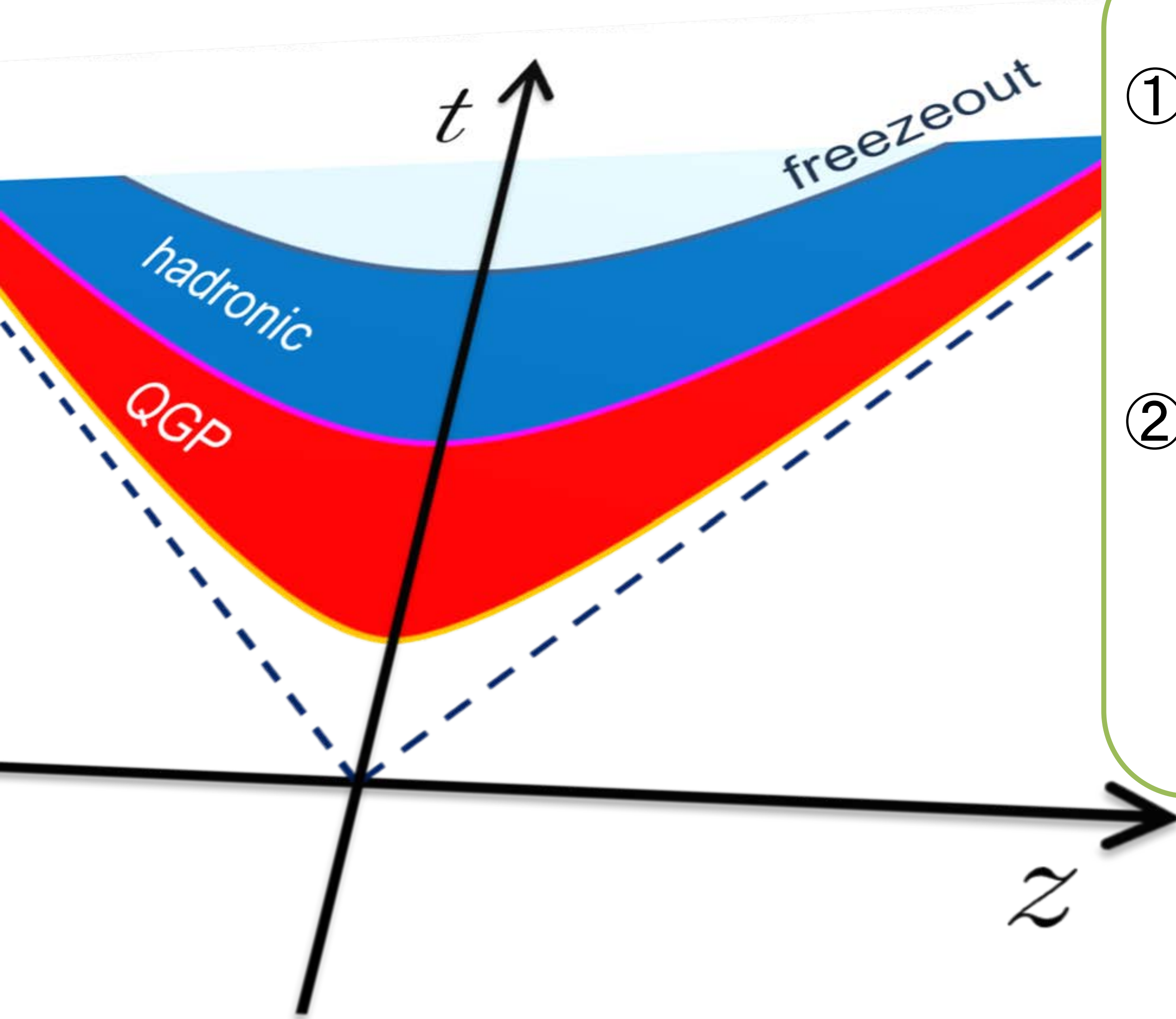
D-measure

$$D = 4\frac{\langle \delta N_Q^2 \rangle}{\langle N_Q^+ + N_Q^- \rangle}$$

- D ~ 3-4 Hadronic
- D ~ 1-1.5 Quark



Time Evolution of Fluctuations



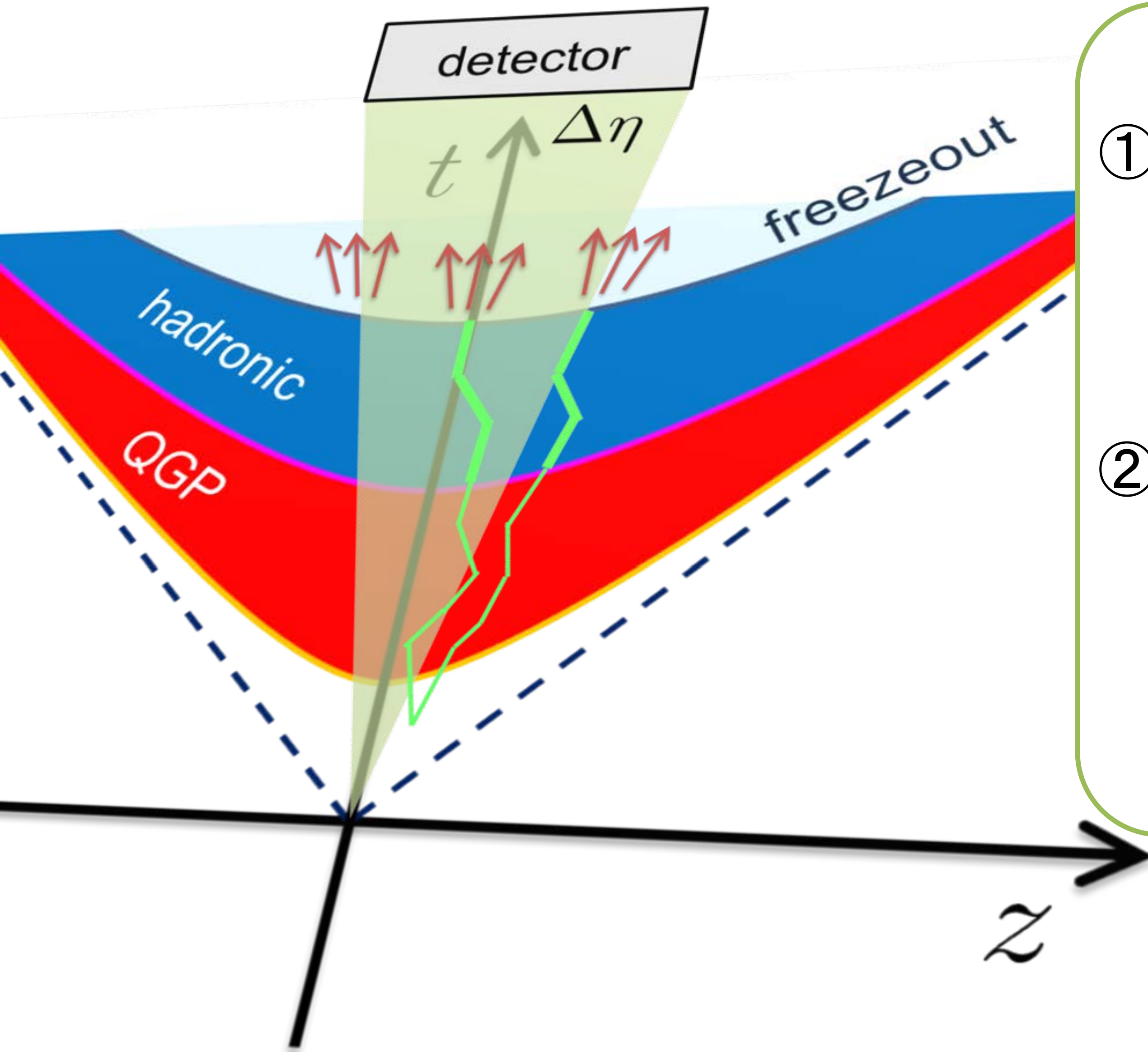
Particle # in Δη

① continues to change until kinetic freezeout due to diffusion.

② changes due to a conversion y → η at kinetic freezeout

"Thermal Blurring"

Time Evolution of Fluctuations



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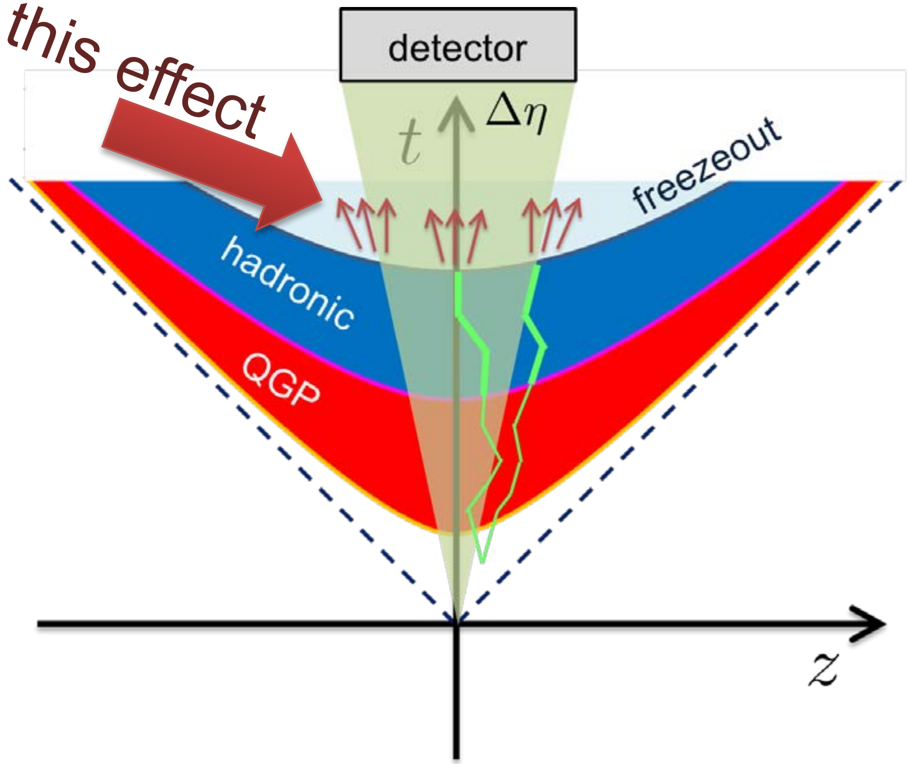
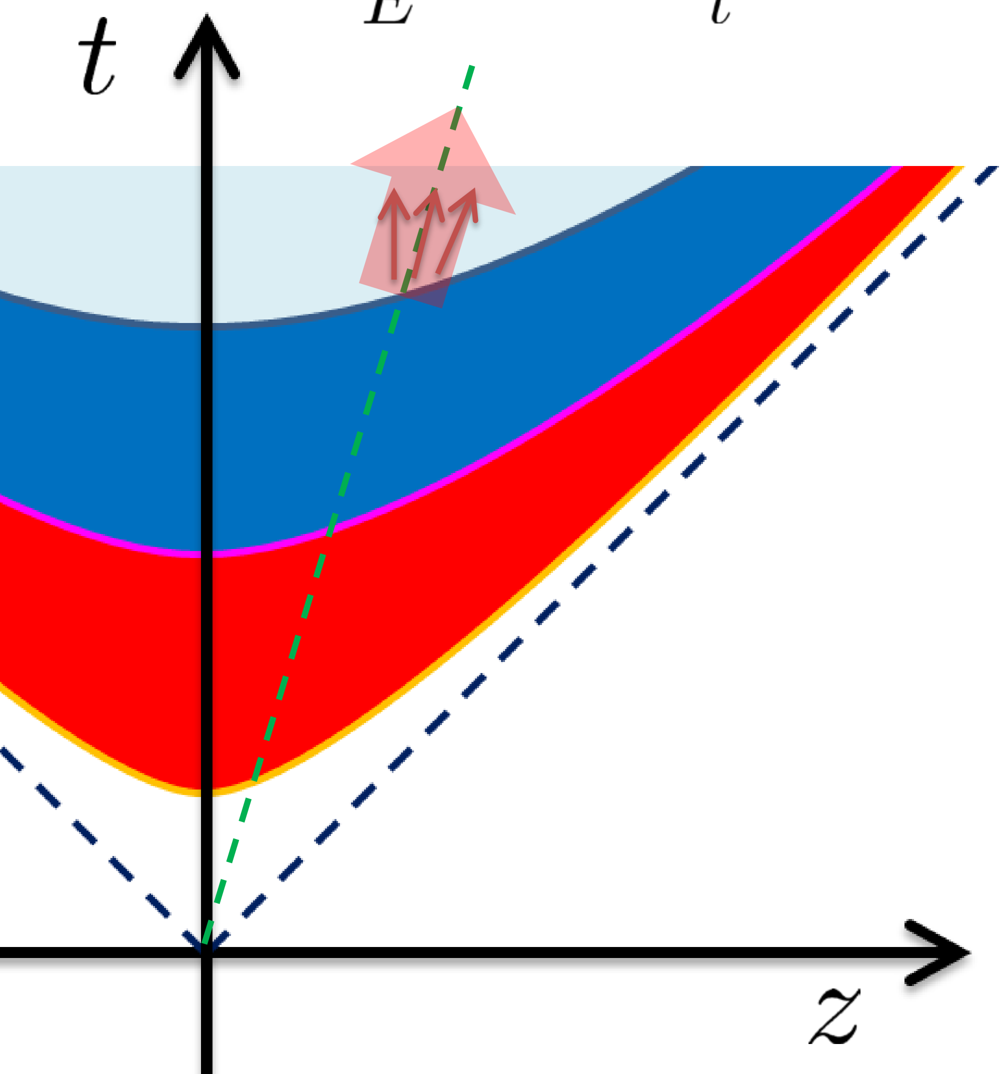
Thermal Blurring



Thermal Blurring

$$\frac{p_z}{E} = v_z = \frac{z}{t}$$



Under Bjorken picture,

coordinate-space rapidity
of medium

$=$

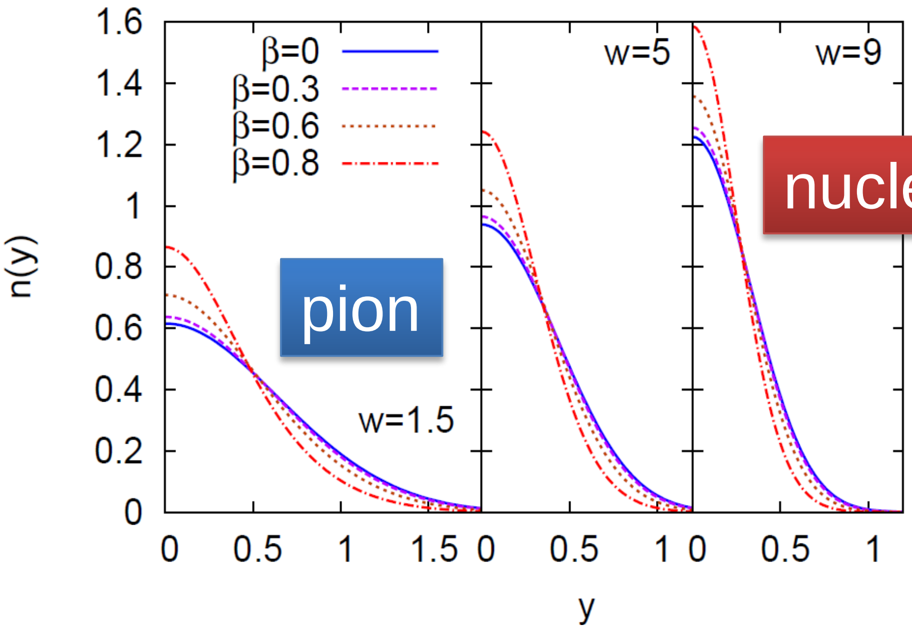
momentum-space rapidity

$\neq$

coordinate-space rapidity
of individual particles

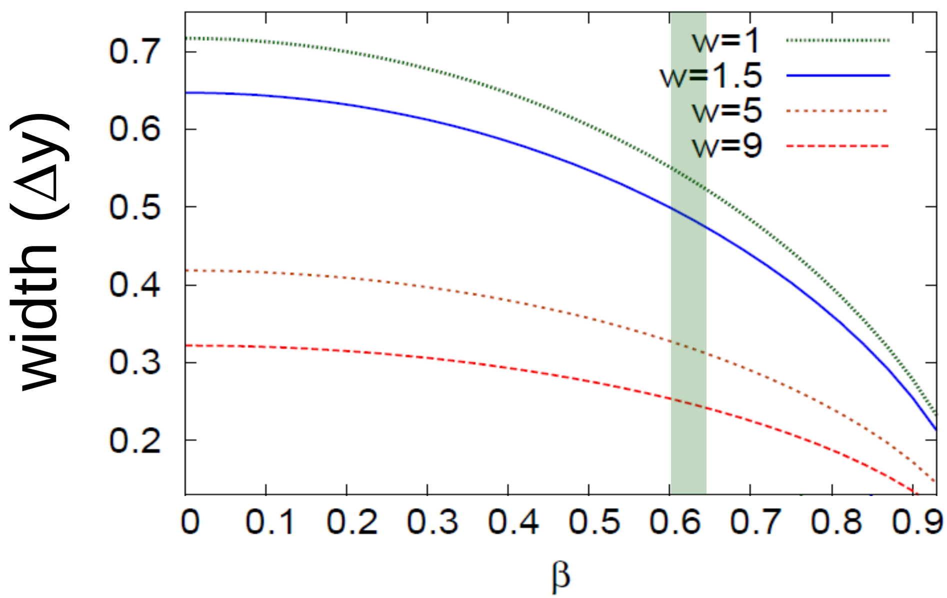
Thermal distribution in η space

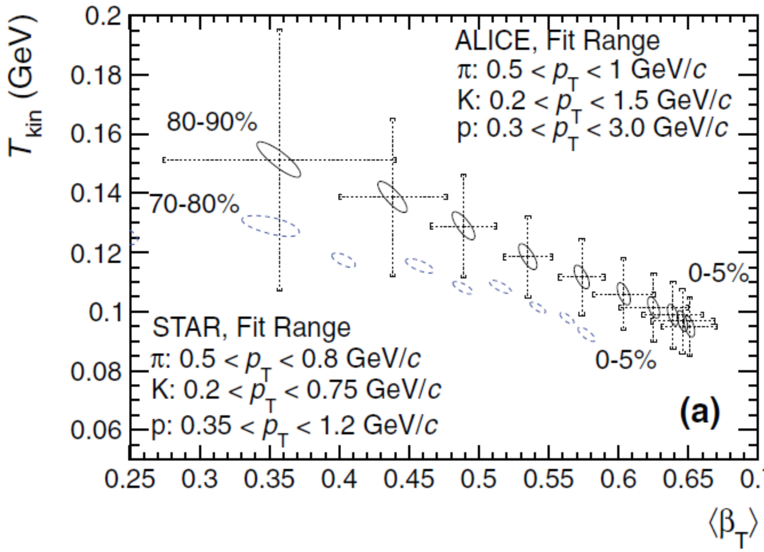
Y. Ohnishi+
in preparation



$$w = \frac{m}{T}$$

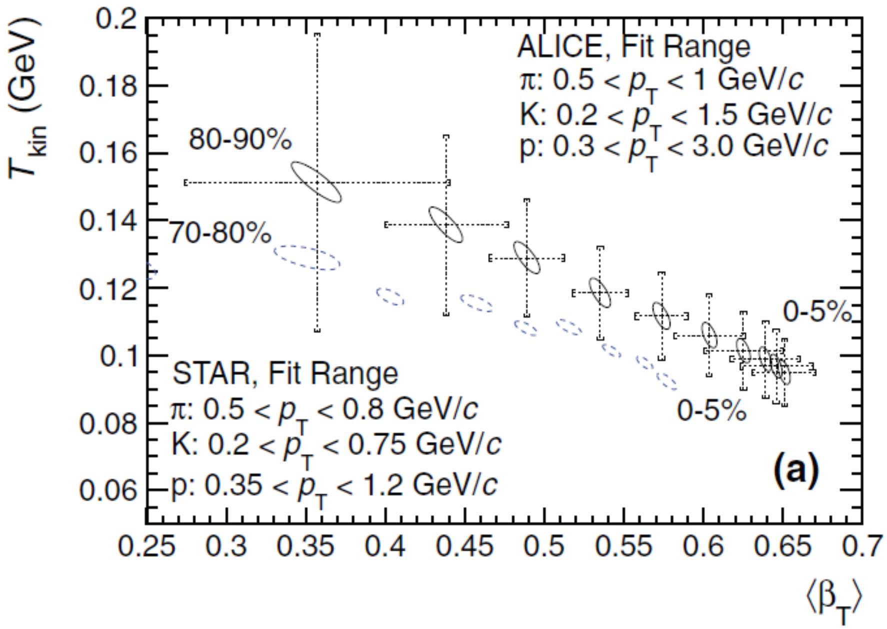
- pions $w \simeq 1.5$
- nucleons $w \simeq 9$

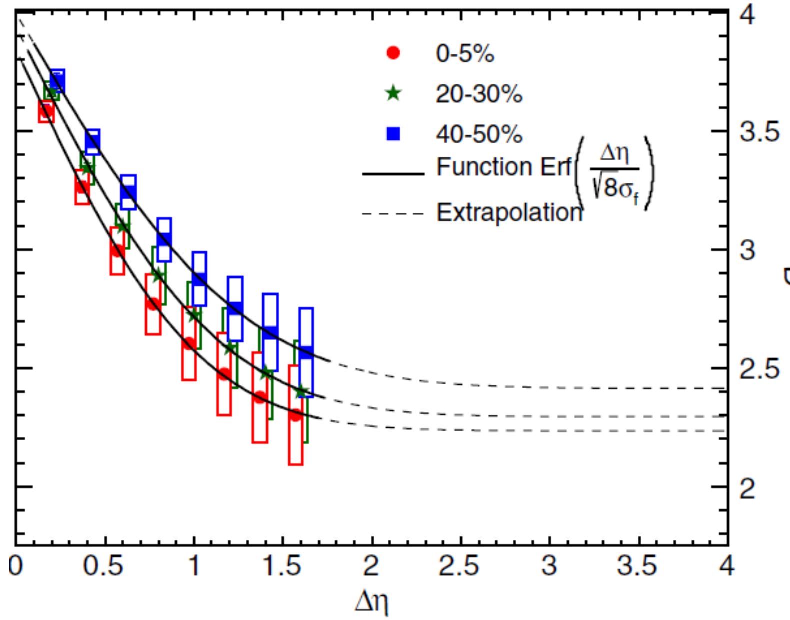




- blast wave
- flat freezeout surface

Centrality Dependence





More central ⇒ { lower T, larger β } ⇒ Weaker blurring

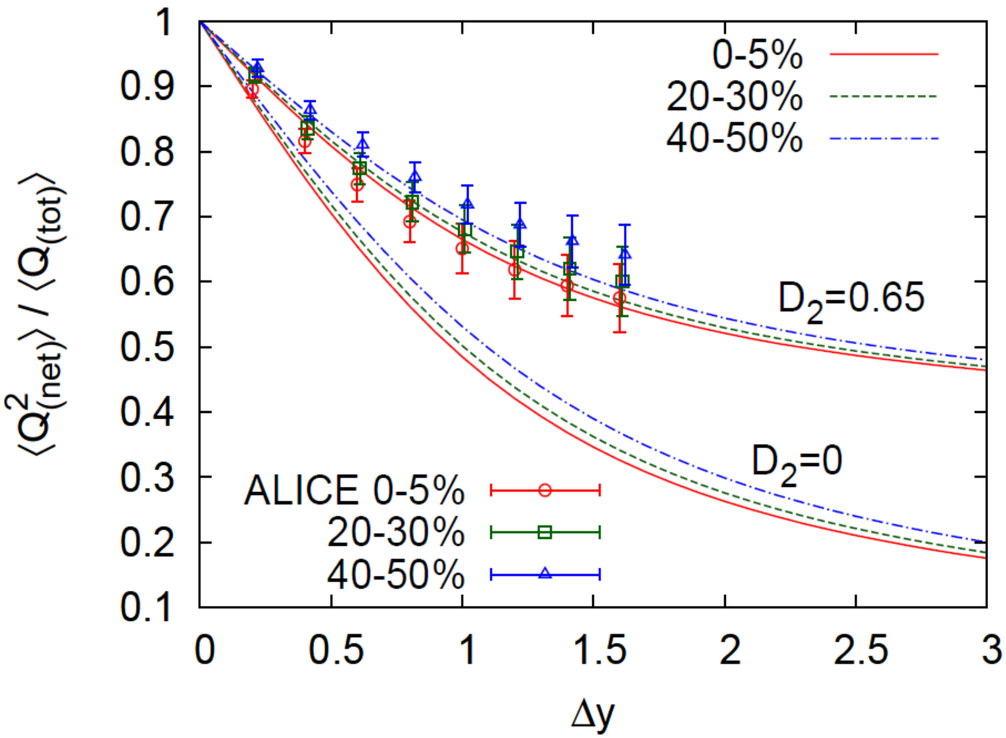
Is the centrality dependence understood solely by the thermal blurring at kinetic f.o.?

Centrality Dependence

$$D_2 = \frac{\langle \delta N_Q^2 \rangle}{\langle \delta N_Q^2 \rangle_{eq.}}$$

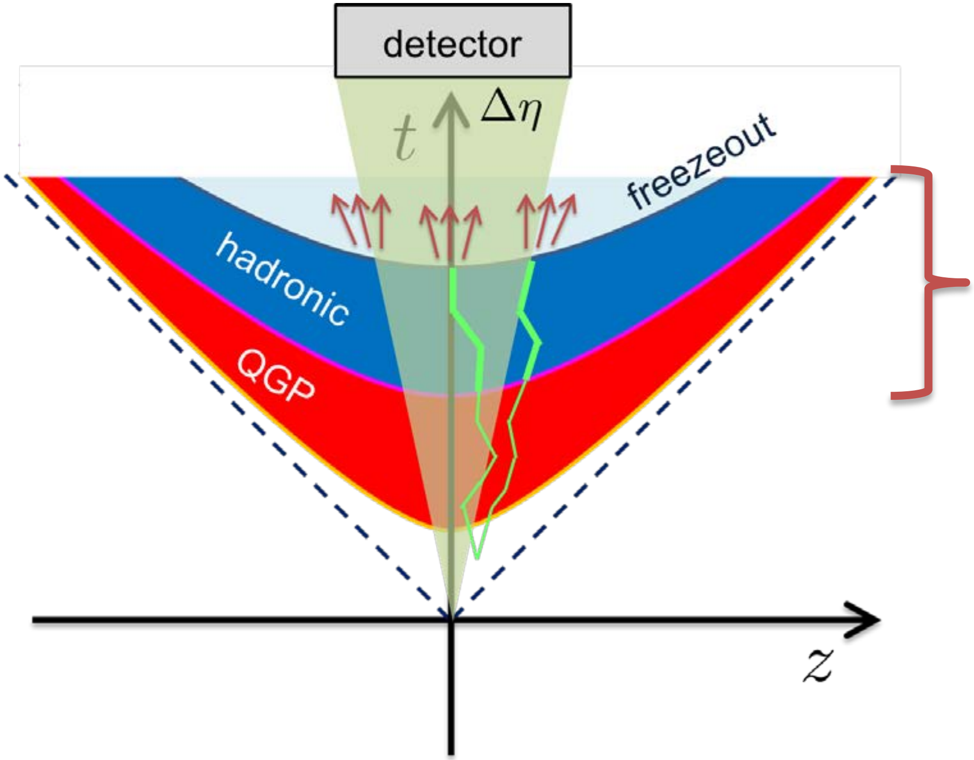
Assumptions:

- Centrality independent cumulant at kinetic f.o.
- Thermal blurring at kinetic f.o.



☐ Centrality dep. of blast wave parameters can qualitatively describe the one of $\langle \delta N_Q^2 \rangle$

Diffusion + Thermal Blurring, Non-Gaussian Cumulants

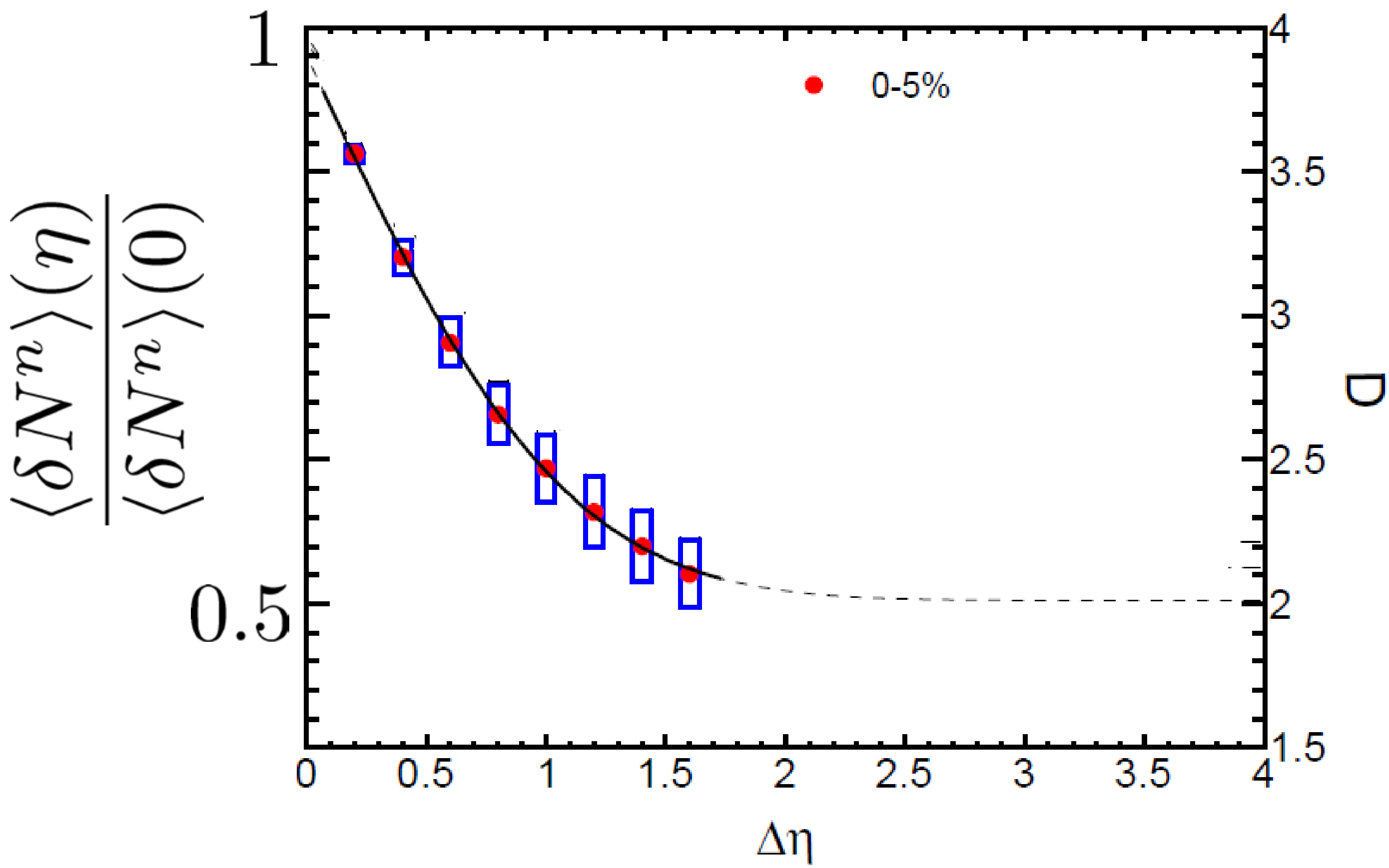


these processes

$\langle \delta N_Q^4 \rangle$ @ LHC ?

How does $\langle \delta N_Q^4 \rangle_c$ behave as a function of $\Delta\eta$?

suppression or enhancement



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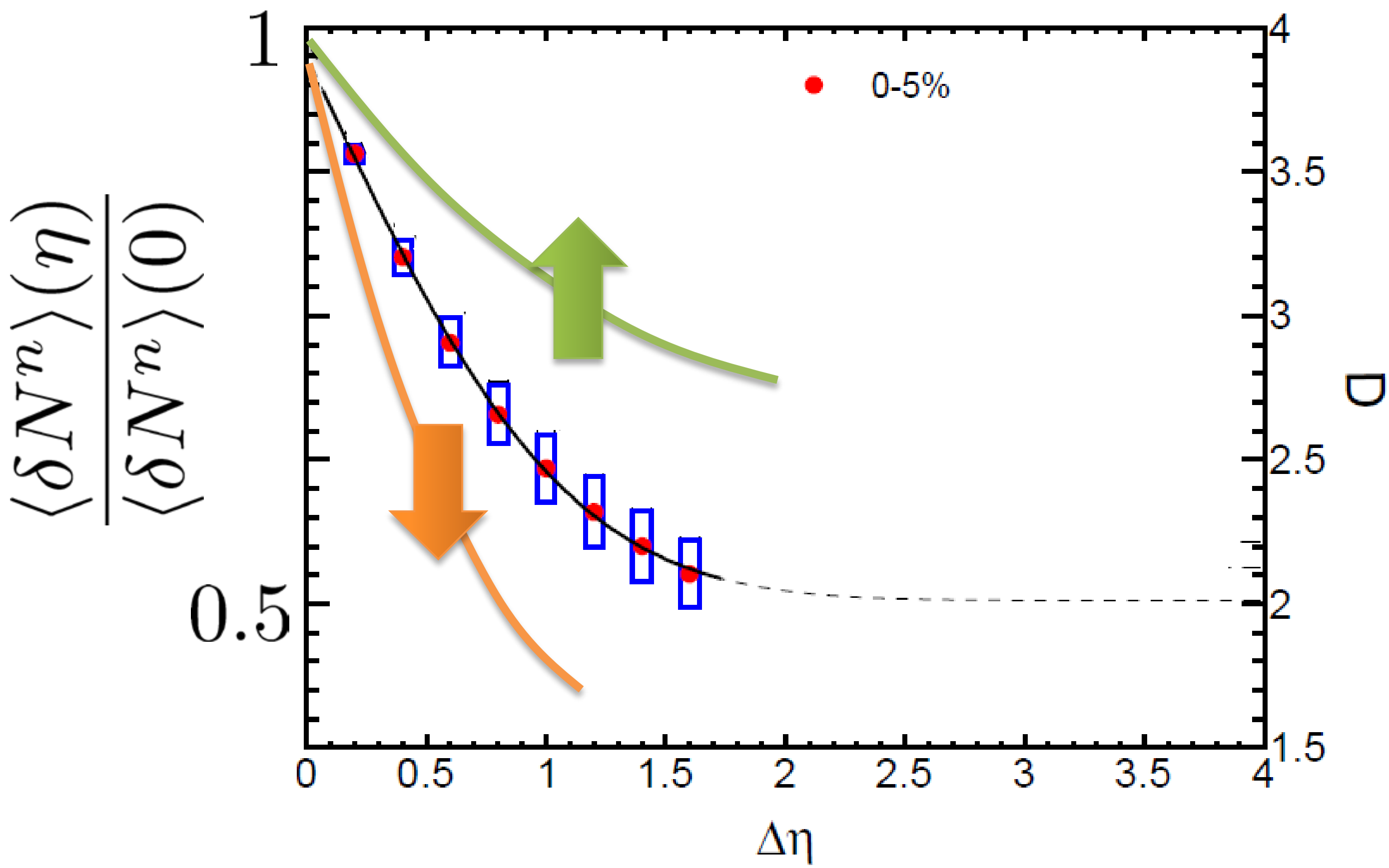


How to Introduce Non-Gaussianity?

Stochastic diffusion equation

$$\partial_\tau n = D\partial_\eta^2 n + \partial_\eta \xi(\eta, \tau)$$

⇒ Fluctuation of *n* is Gaussian in equilibrium

How to Introduce Non-Gaussianity?

Stochastic diffusion equation

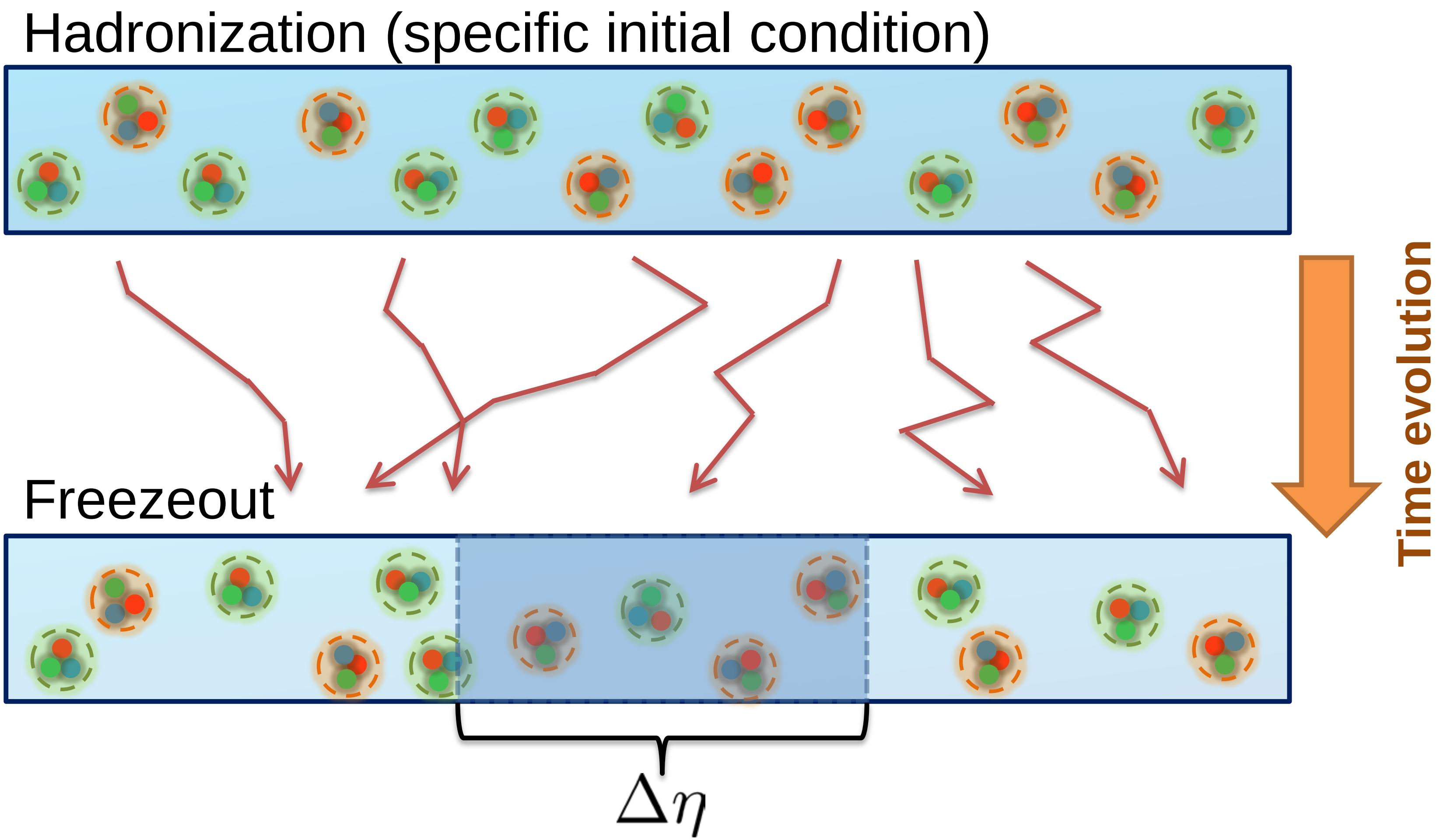
$$\partial_\tau n = D\partial_\eta^2 n + \partial_\eta \xi(\eta,\tau)$$

Fluctuation of *n* is Gaussian in equilibrium

- Choices to introduce non-Gaussianity in equil.:
  - *n* dependence of diffusion constant *D*(*n*)
  - colored noise
  - discretization of *n* ← **our choice**

REMARK: Fluctuations measured in HIC are almost Poissonian.

A Brownian Particle's Model



Initial distribution + motion of each particle
→ cumulants of particle # in $\Delta\eta$

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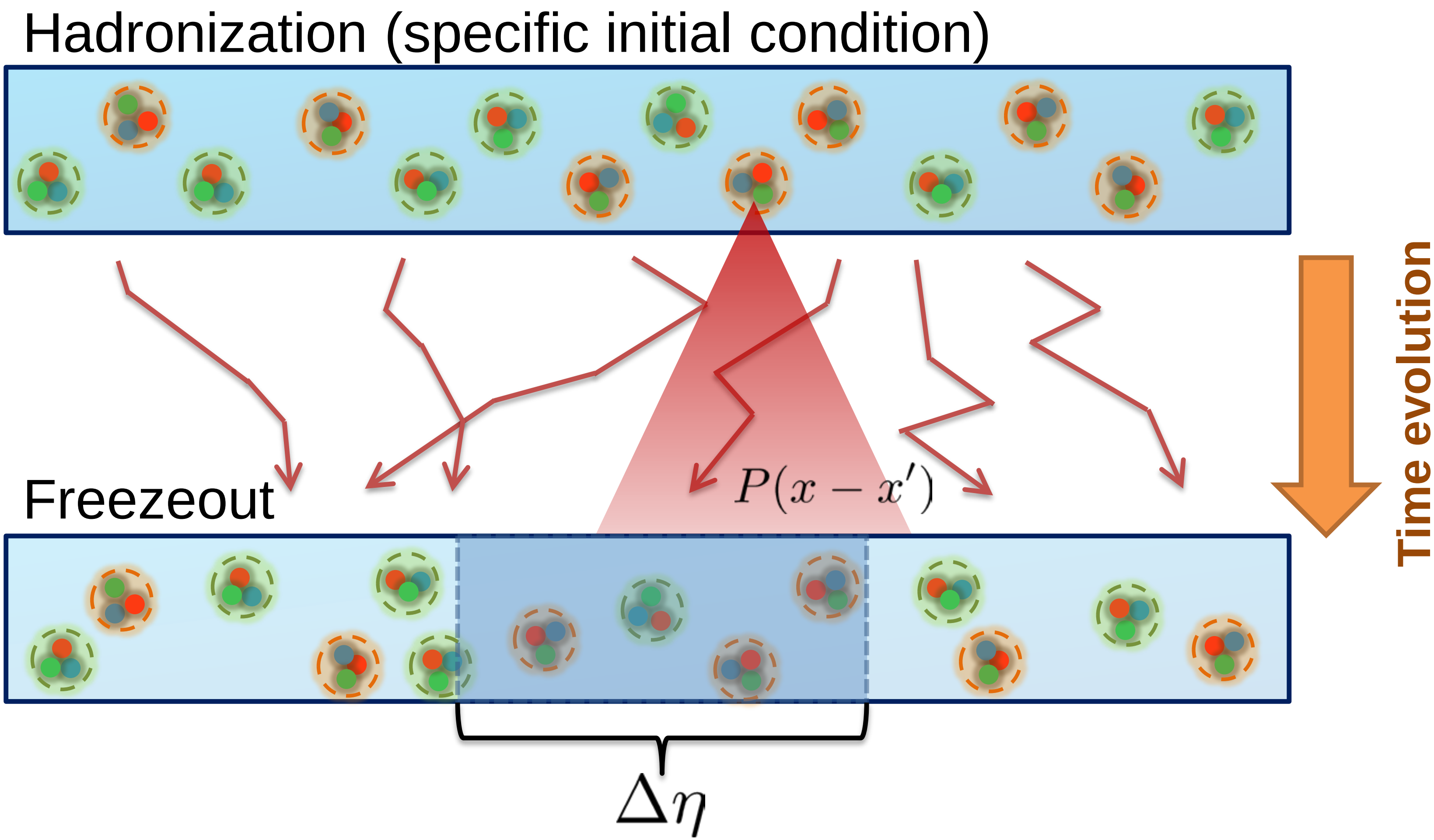

Initial distribution + motion of each particle
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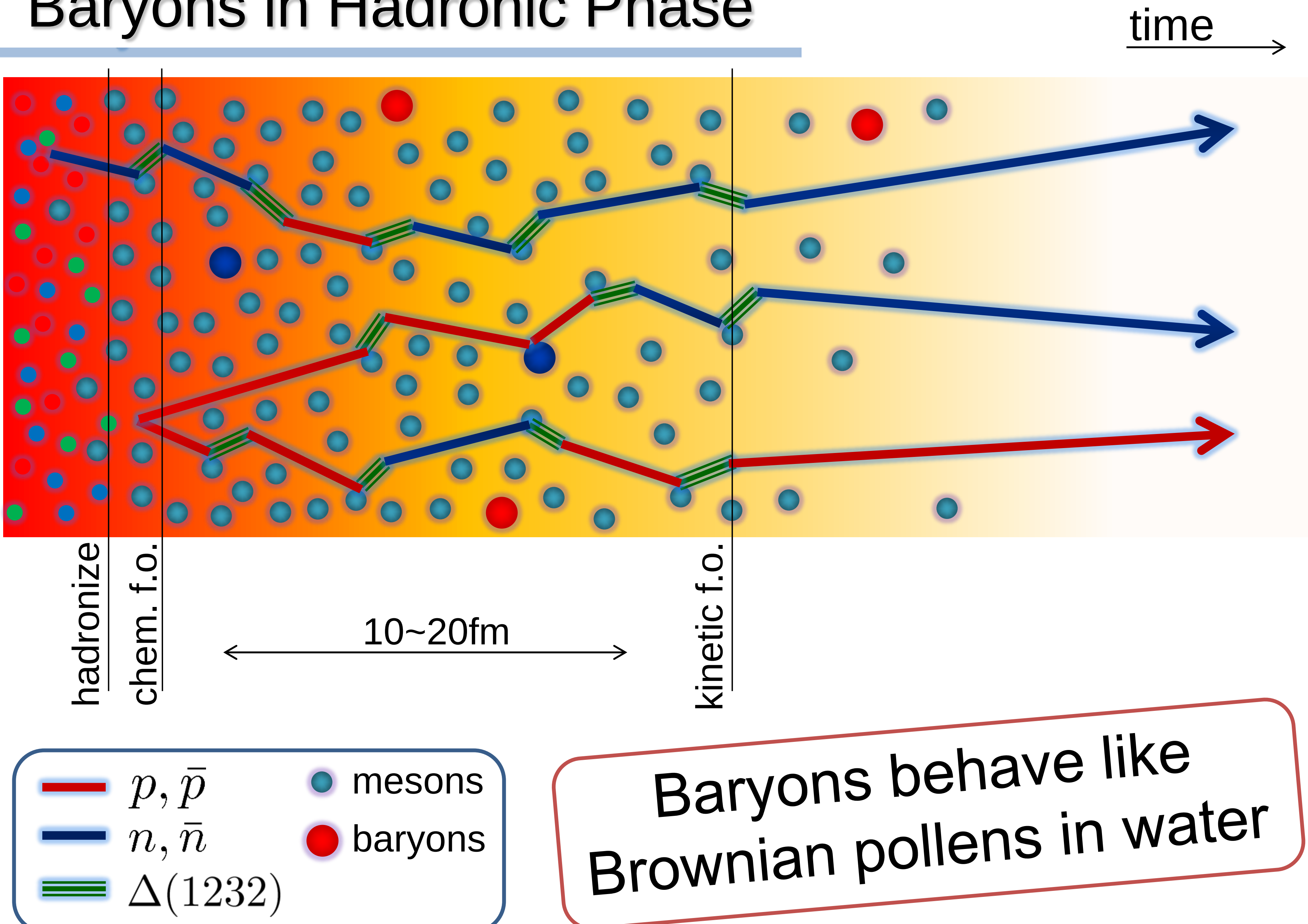
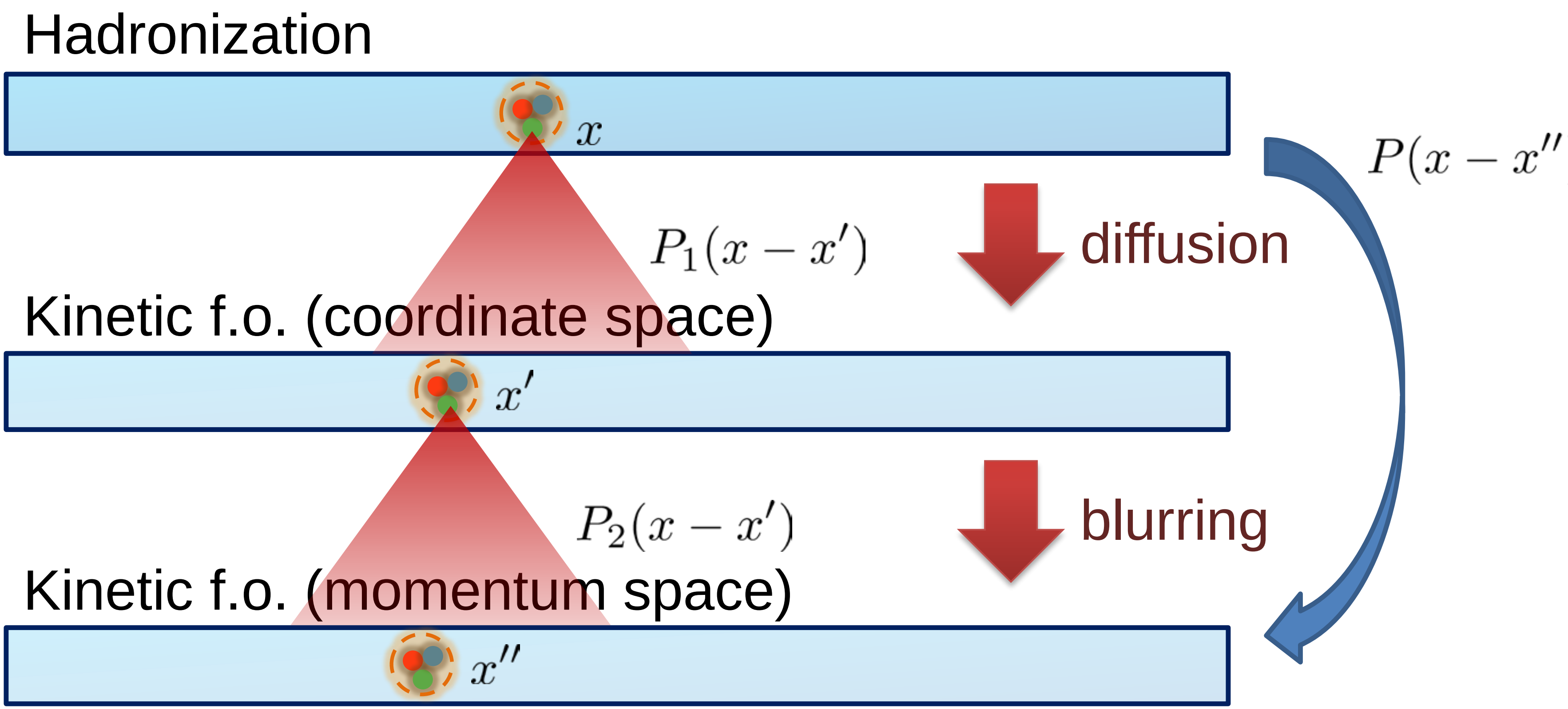
Baryons in Hadronic Phase



Baryons behave like Brownian pollens in water

Diffusion + Thermal Blurring

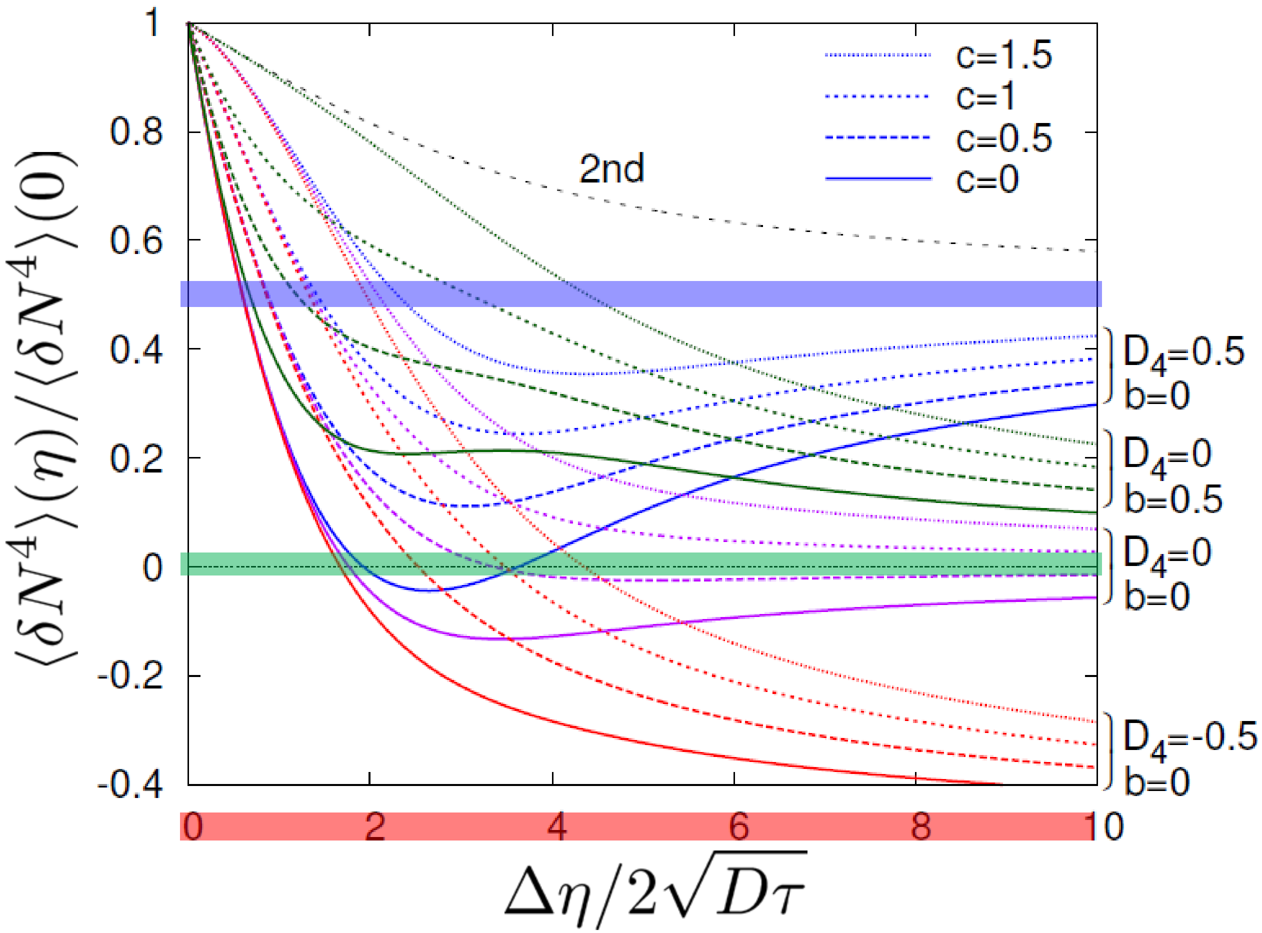


Total diffusion: $P(x - x'') = \int dx' P_1(x - x') P_2(x' - x'')$

- Diffusion + thermal blurring = described by a single P(x)
- Both are consistent with Gaussian → Single Gaussian

$\Delta\eta$ Dependence: 4[th] order

MK, NPA (2015)



Initial Condition

$$D_4 = \frac{\langle Q^4_{(\mathrm{net})}\rangle_c}{\langle Q_{(\mathrm{tot})}\rangle}$$

$$b = \frac{\langle Q^2_{(\mathrm{net})} Q_{(\mathrm{tot})}\rangle_c}{\langle Q_{(\mathrm{net})}\rangle}$$

$$c = \frac{\langle Q^2_{(\mathrm{tot})}\rangle_c}{\langle Q_{(\mathrm{tot})}\rangle}$$

$$D_2 = \frac{\langle Q^2_{(\mathrm{net})}\rangle_c}{\langle Q_{(\mathrm{tot})}\rangle} = 0.5$$

Characteristic $\Delta\eta$ dependences!

Δη Dependence: 4th order

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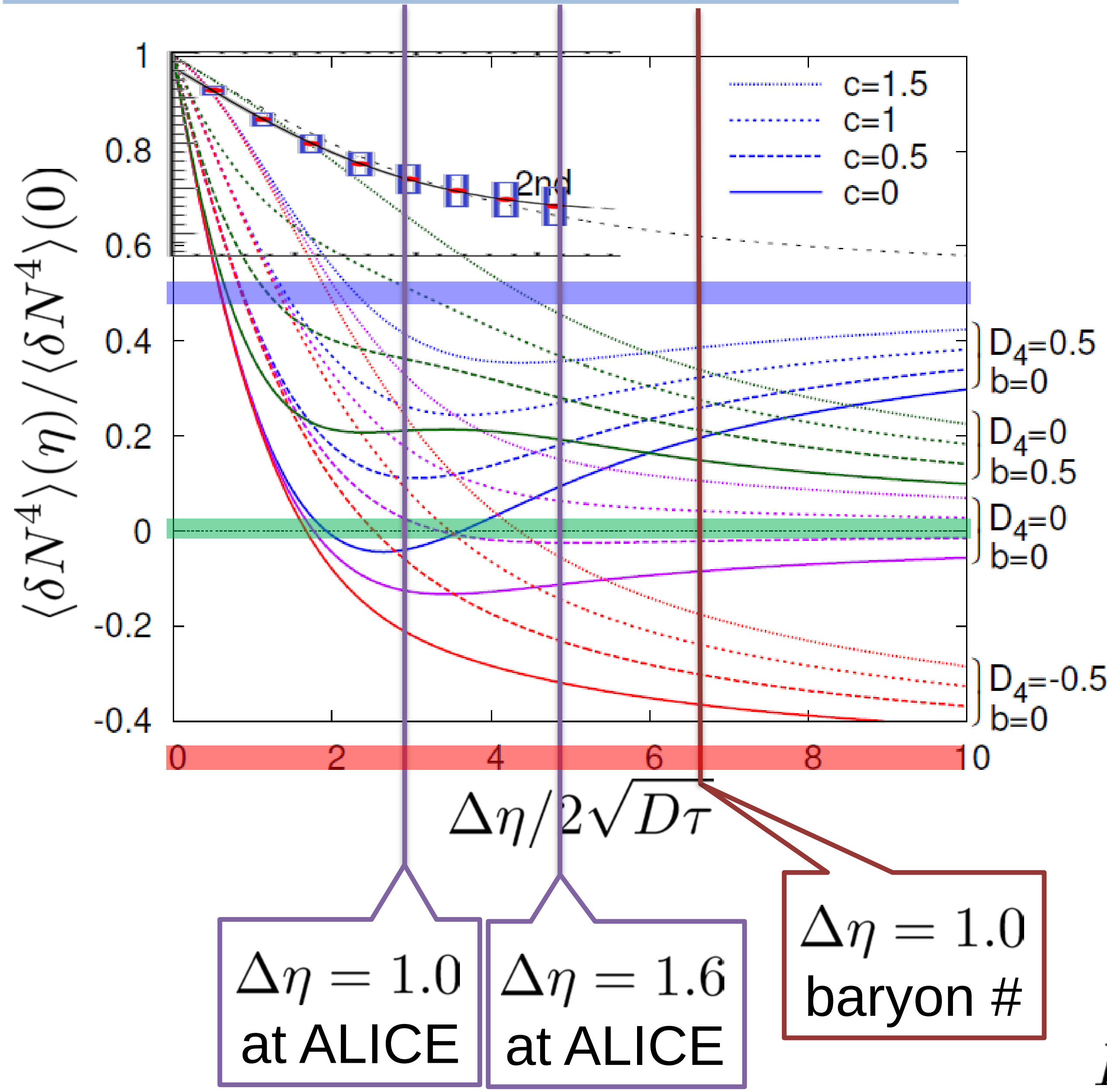

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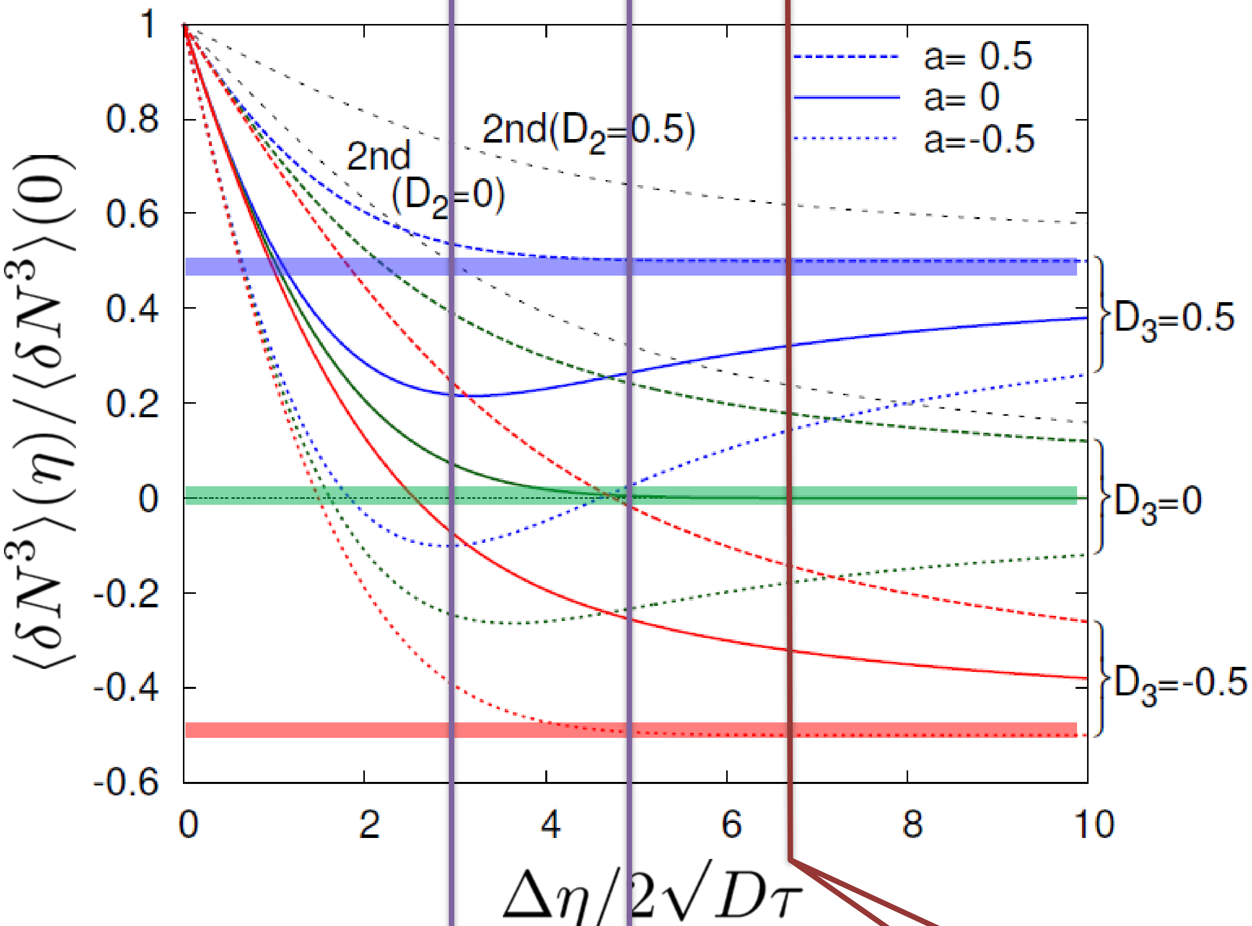
$$D \sim M^{-1}$$

Δη Dependence: 3rd order

MK, NPA (2015)



$\Delta\eta = 1.0$
at ALICE

$\Delta\eta = 1.6$
at ALICE

$\Delta\eta = 1.0$
baryon #

Initial Condition

$$D_3 = \frac{\langle Q^3_{(\mathrm{net})} \rangle_c}{\langle Q_{(\mathrm{net})} \rangle}$$

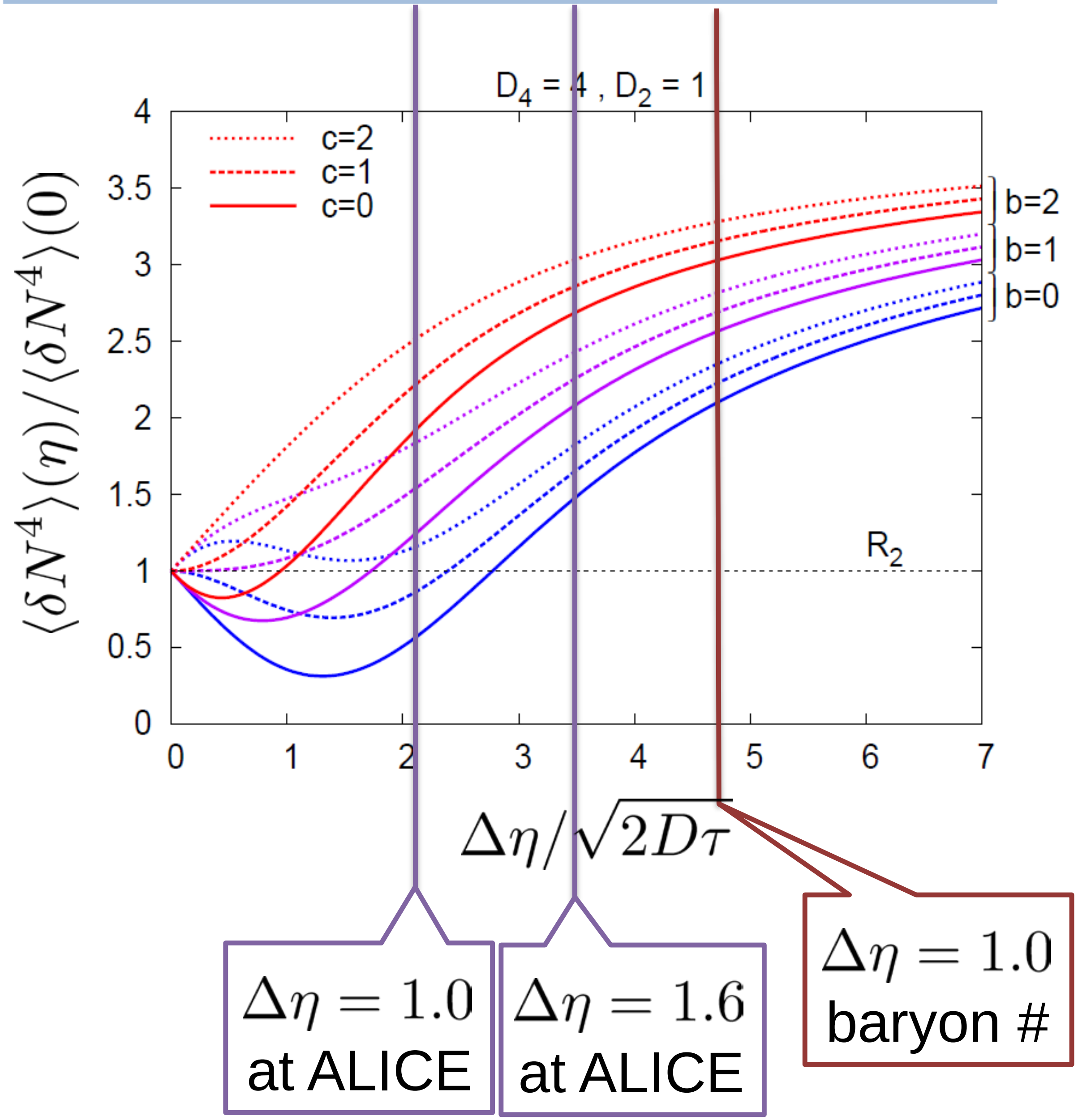
$$a = \frac{\langle Q_{(\mathrm{net})} Q_{(\mathrm{tot})} \rangle_c}{\langle Q_{(\mathrm{net})} \rangle}$$

$$D_2 = \frac{\langle Q^2_{(\mathrm{net})} \rangle_c}{\langle Q_{(\mathrm{tot})} \rangle} = 0.5$$

$$D \sim M^{-1}$$

4^{th} order : Large Initial Fluc.

MK, NPA (2015)



Initial Condition

$$D_4 = \frac{\langle Q^4_{(\mathrm{net})} \rangle_c}{\langle Q_{(\mathrm{tot})} \rangle} = 4$$

$$b = \frac{\langle Q^2_{(\mathrm{net})} Q_{(\mathrm{tot})} \rangle_c}{\langle Q_{(\mathrm{net})} \rangle}$$

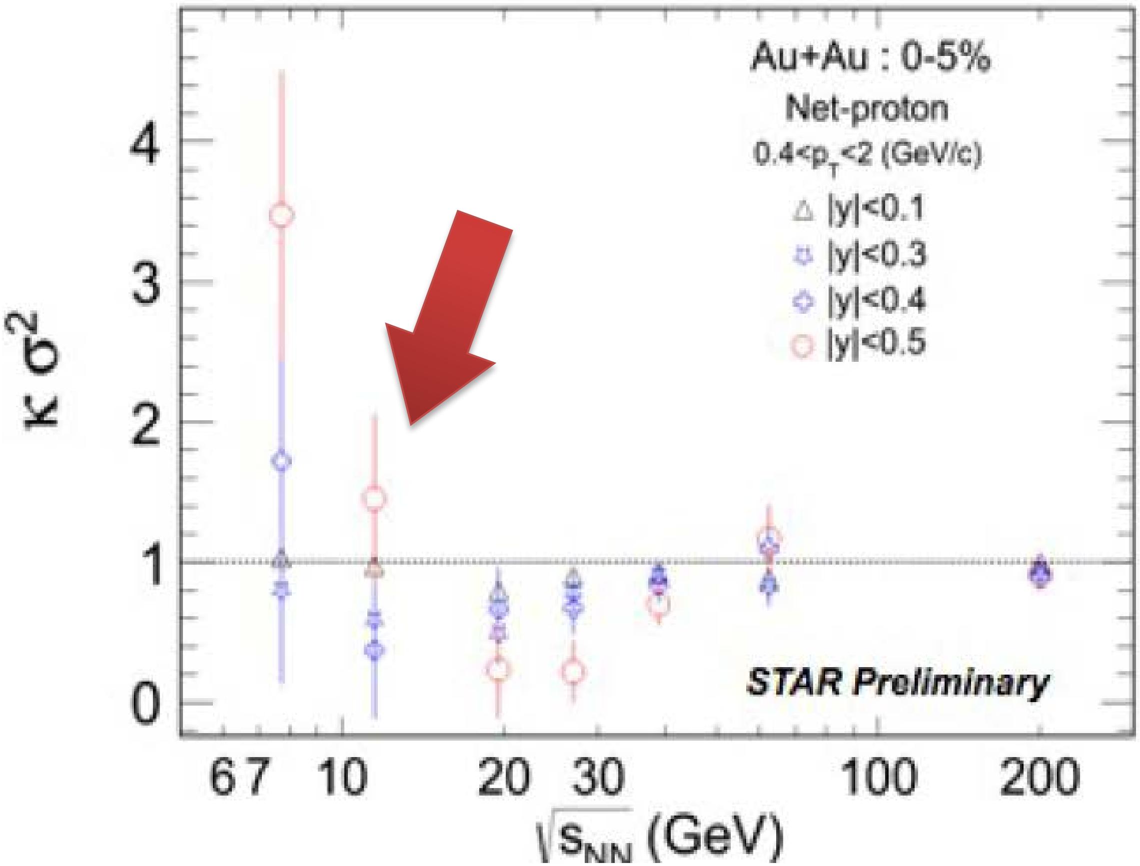
$$c = \frac{\langle Q^2_{(\mathrm{tot})} \rangle_c}{\langle Q_{(\mathrm{tot})} \rangle}$$

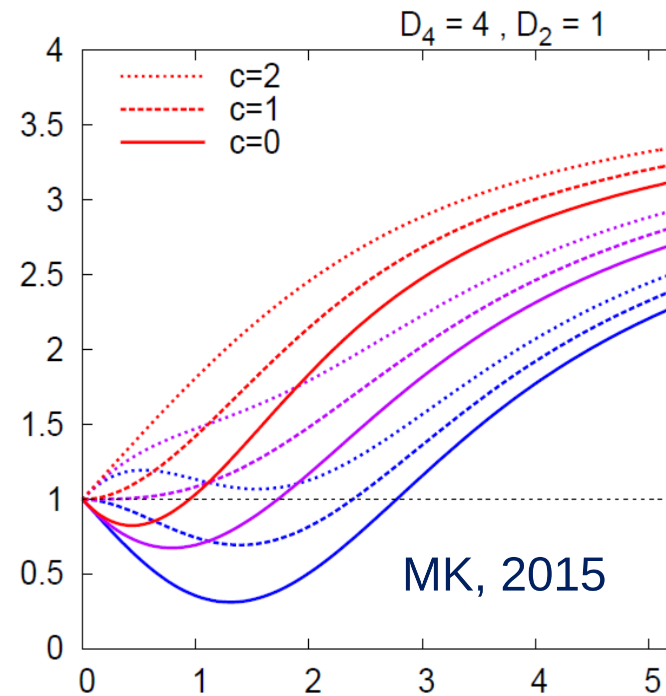
$$D_2 = \frac{\langle Q^2_{(\mathrm{net})} \rangle_c}{\langle Q_{(\mathrm{tot})} \rangle} = 1$$

$$D \sim M^{-1}$$

Δη Dependence @ STAR

from X. Luo, CPOD2014





Non-monotonic dependence on Δη ?

Summary

Plenty of information in $\Delta\eta$ and centrality dependences of various cumulants

$$\langle N_Q^2\rangle_c,\ \langle N_Q^3\rangle_c,\ \langle N_Q^4\rangle_c,\ \langle N_B^2\rangle_c,\ \langle N_B^3\rangle_c,\ \langle N_B^4\rangle_c,\ \langle N_S^2\rangle_c,\ \cdots$$

and those of non-conserved charges, mixed cumulants…

With $\Delta\eta$ dep. we can explore

- primordial thermodynamics
- non-thermal and transport property
- effect of thermal blurring

Future Studies

Experimental side:

- rapidity window dependences
- baryon number cumulants
- consistency between RHIC and LHC

Theoretical side:

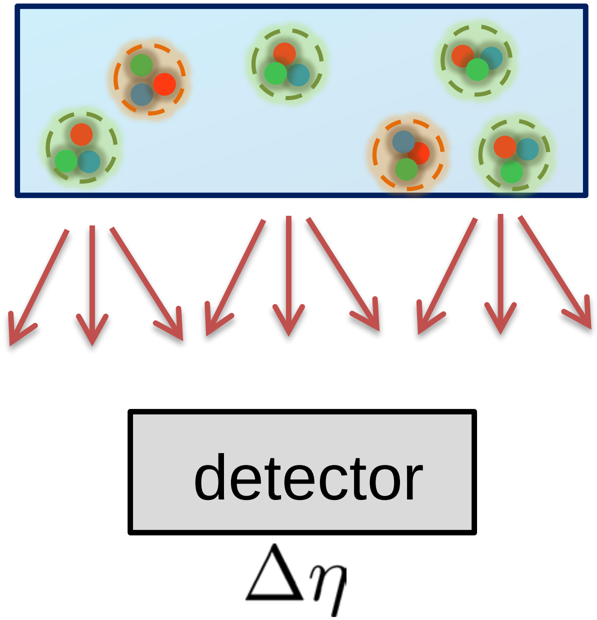
- rapidity window dependences in dynamical models
- description of non-equilibrium non-Gaussianity
- accurate measurements on the lattice

Both sides:

- Compare theory and experiment carefully
- Do not use a fixed $\Delta\eta$ cumulant for comparison!!!

Very Low Energy Collisions

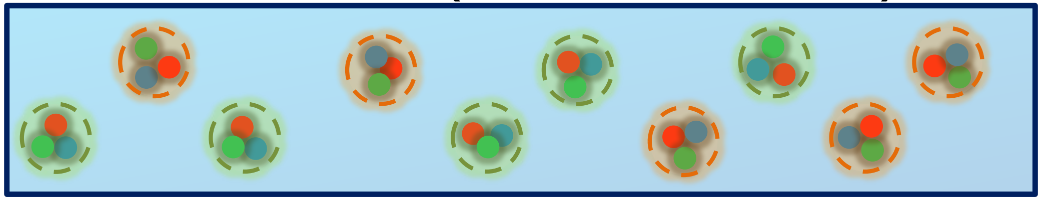
- Large contribution of global charge conservation
- Violation of Bjorken scaling



Fluctuations at low √s should be interpreted carefully!
Comparison with statistical mechanics would not make sense…

Initial Condition @ Hadronization

Hadronization (initial condition)



- Boost invariance / infinitely long system
- Local equilibration / local correlation

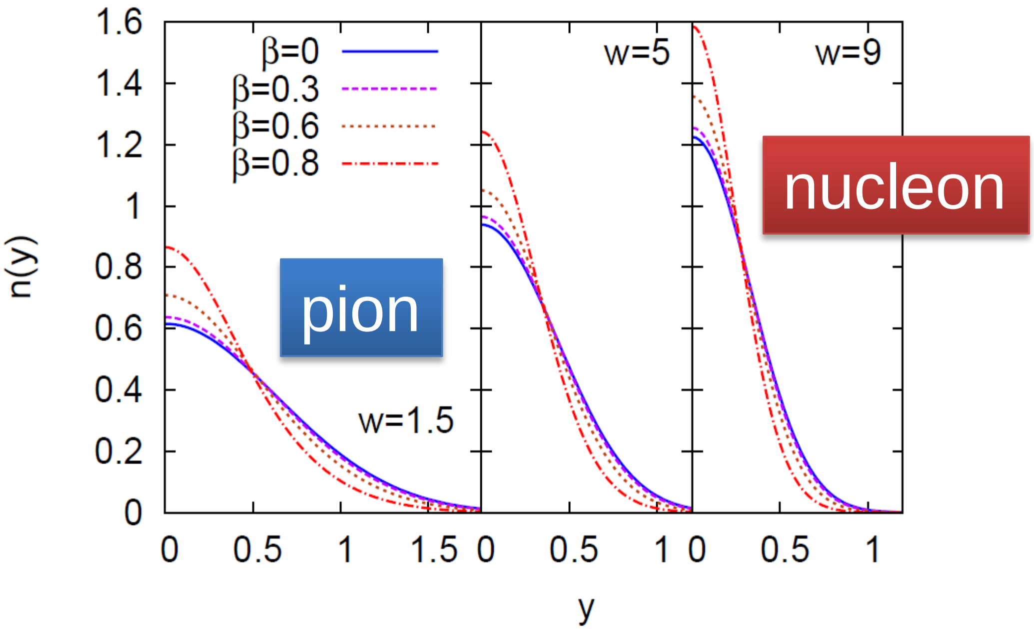
$\langle \bar{Q}^2 \rangle_c, \ \langle \bar{Q}^3 \rangle_c, \ \langle \bar{Q}^4 \rangle_c$ | $\langle \bar{Q}^2 Q_{(\mathrm{tot})} \rangle_c$ | $\langle Q^2_{(\mathrm{tot})} \rangle_c, \langle Q_{(\mathrm{net})} Q_{(\mathrm{tot})} \rangle_c$

suppression owing to local charge conservation

strongly dependent on hadronization mechanism

Thermal distribution in η space

Y. Ohnishi+
in preparation



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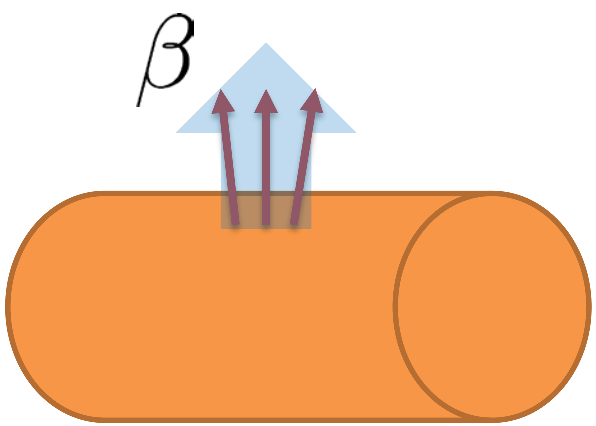
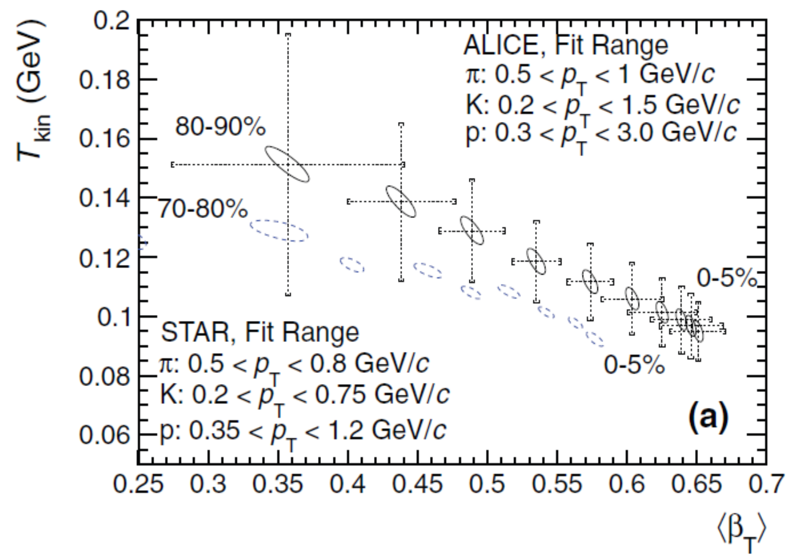
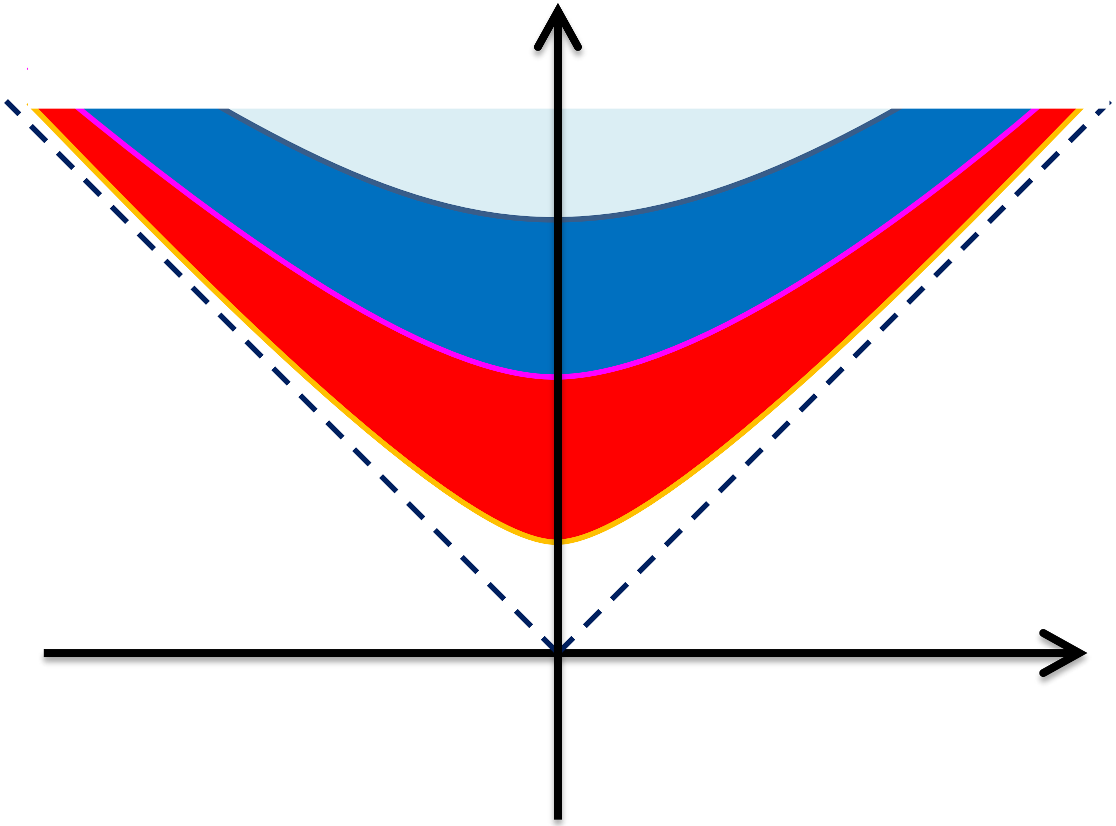


Blast wave squeezes the distribution in rapidity space



- blast wave
- flat freezeout surface

Time Evolution of Fluctuations



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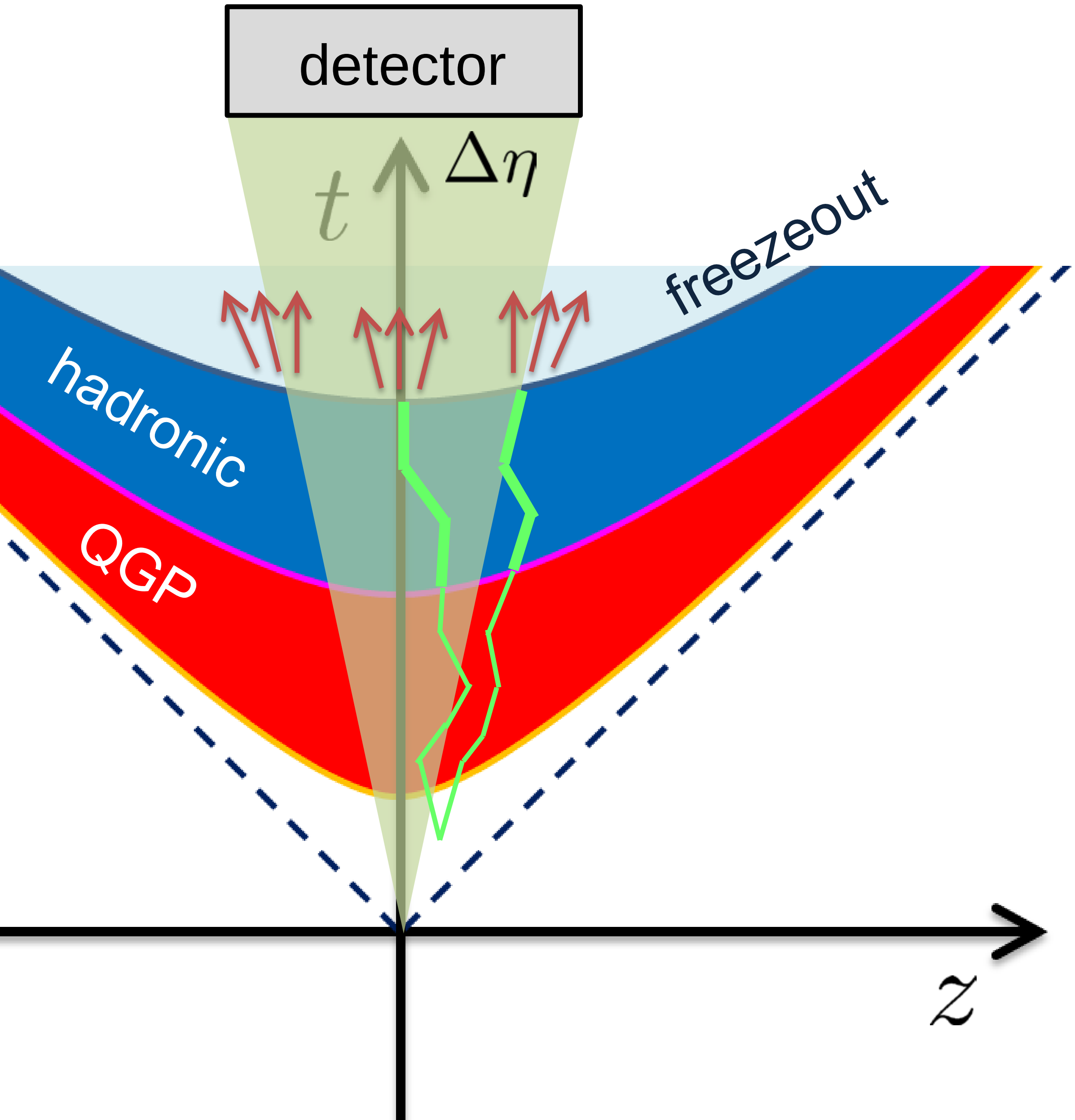

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