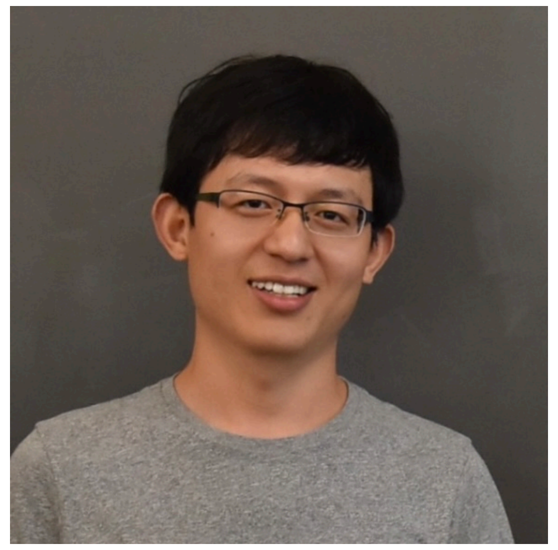
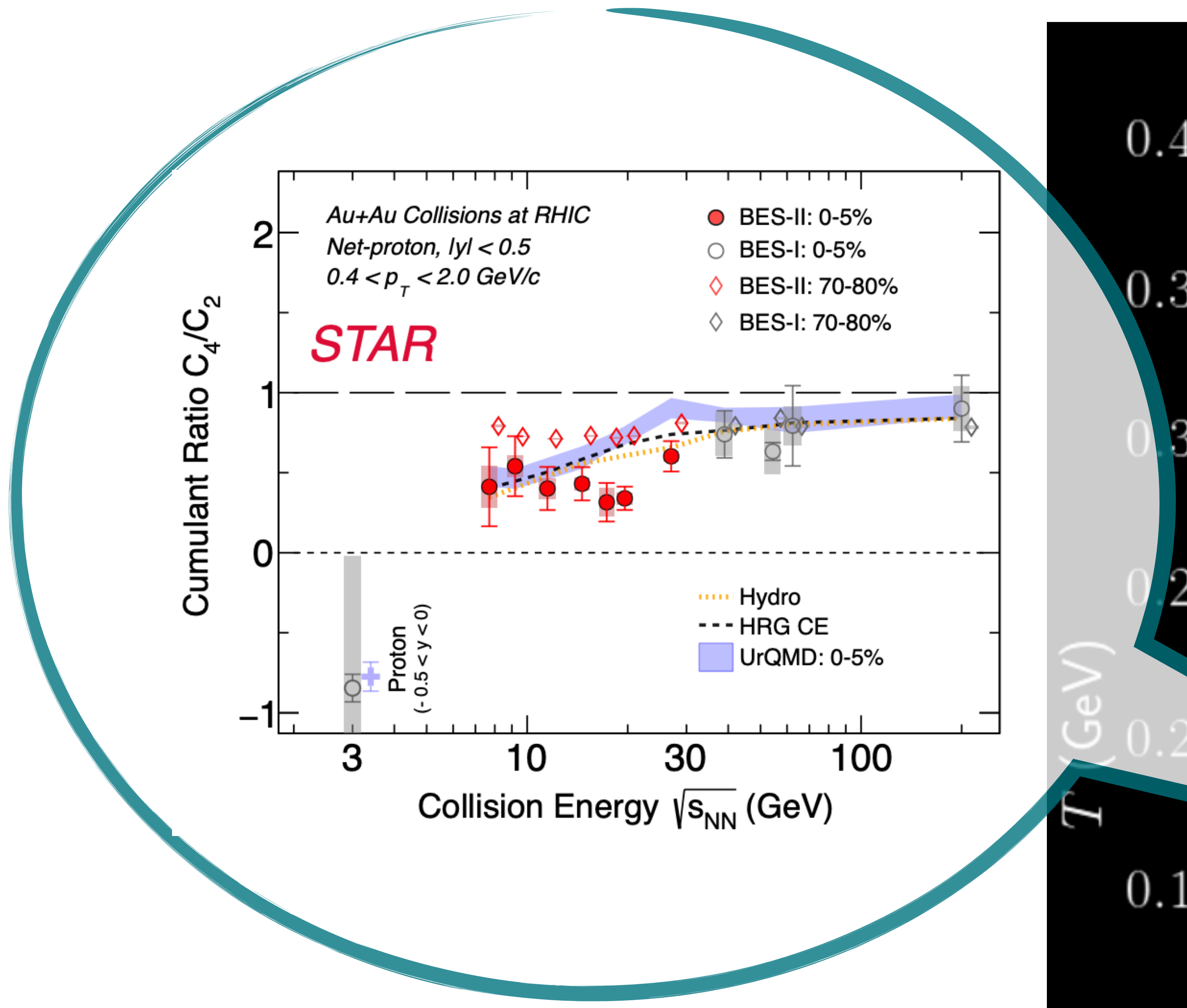
Baseline for net-baryon cumulant in rapidity scan

Phys. Rev. C **109**, 034906 (2024)

Jianing Li (CCNU), Lipei Du (LBNL) and Shuzhe Shi (Tsinghua)



QCD phase diagram & critical endpoint (CEP)



"Extend measurements to even higher orders of fluctuations"

[*"Precision Measurement of Net-proton Number Fluctuations in Au+Au Collisions at RHIC"*]

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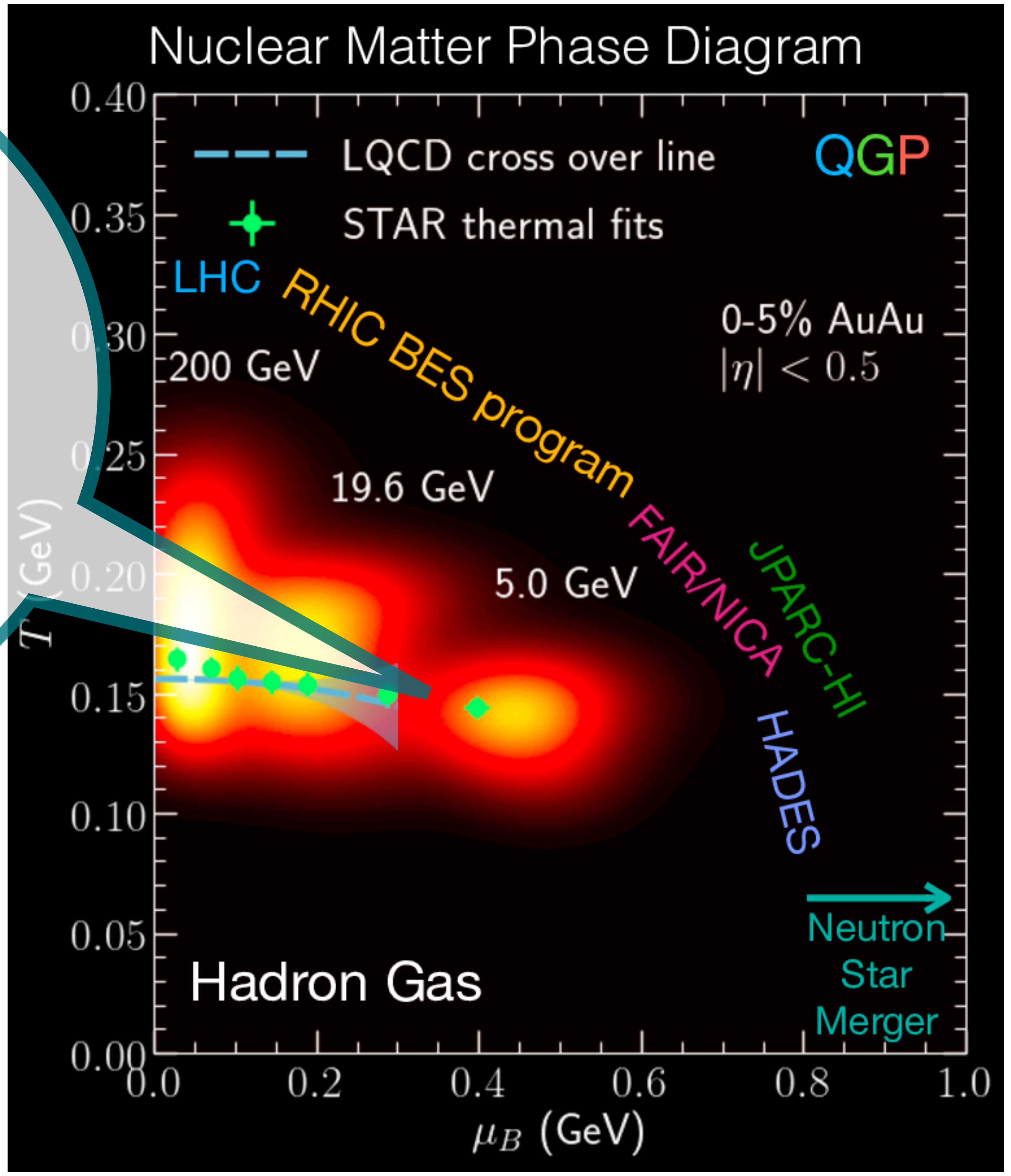
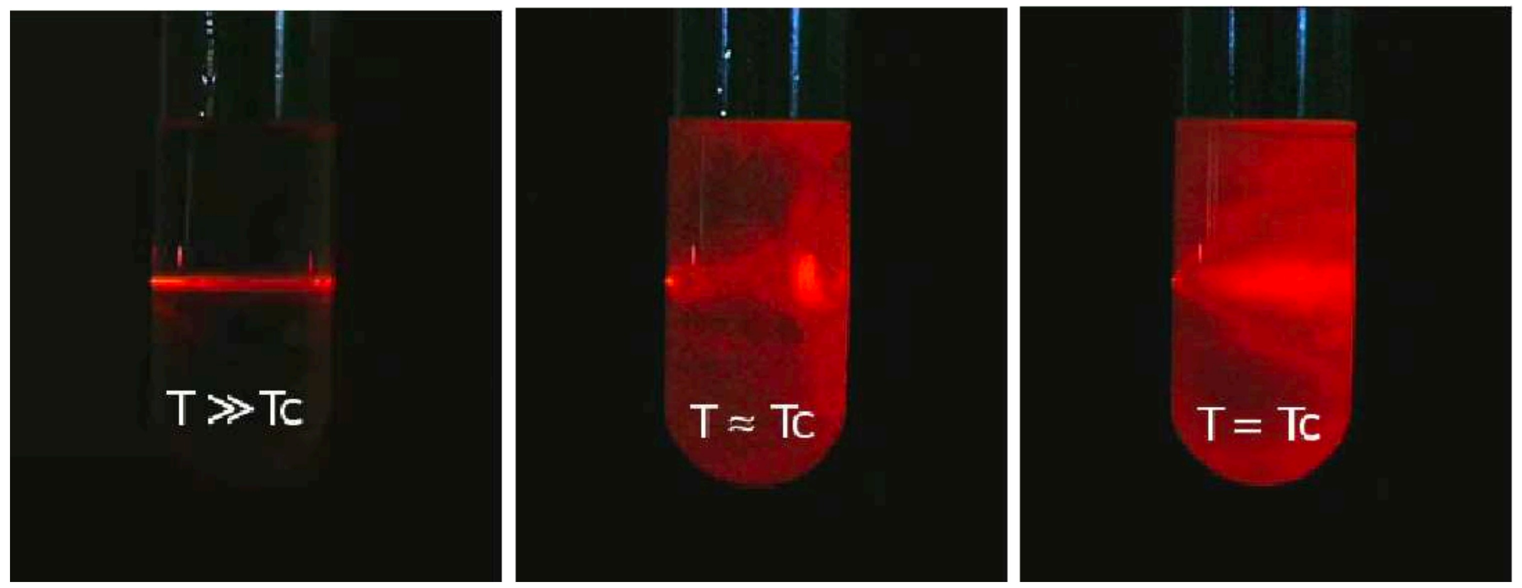


Beam energy scan & QCD phase diagram

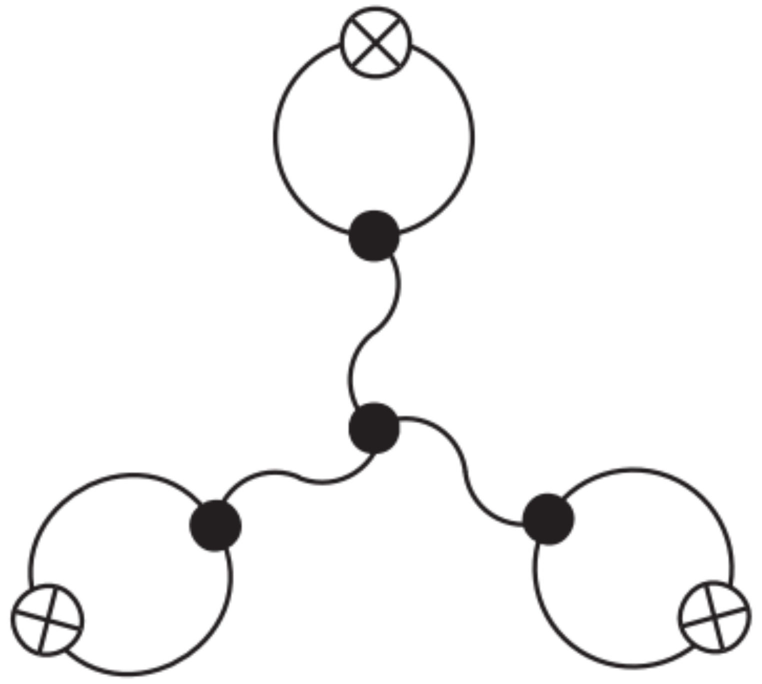
C. Shen, *in 28th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions*

Critical point: large ξ & fluctuations

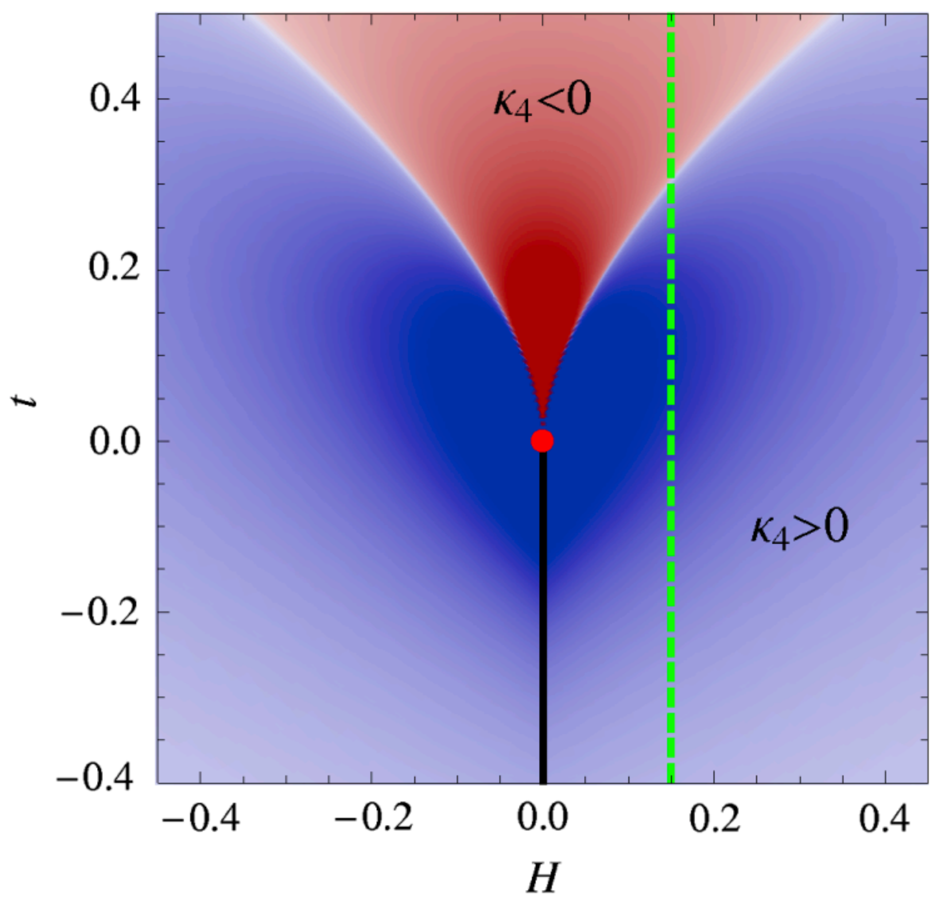


Enhancement

$$\kappa^n \propto \xi^{\frac{5}{2}n-3}$$

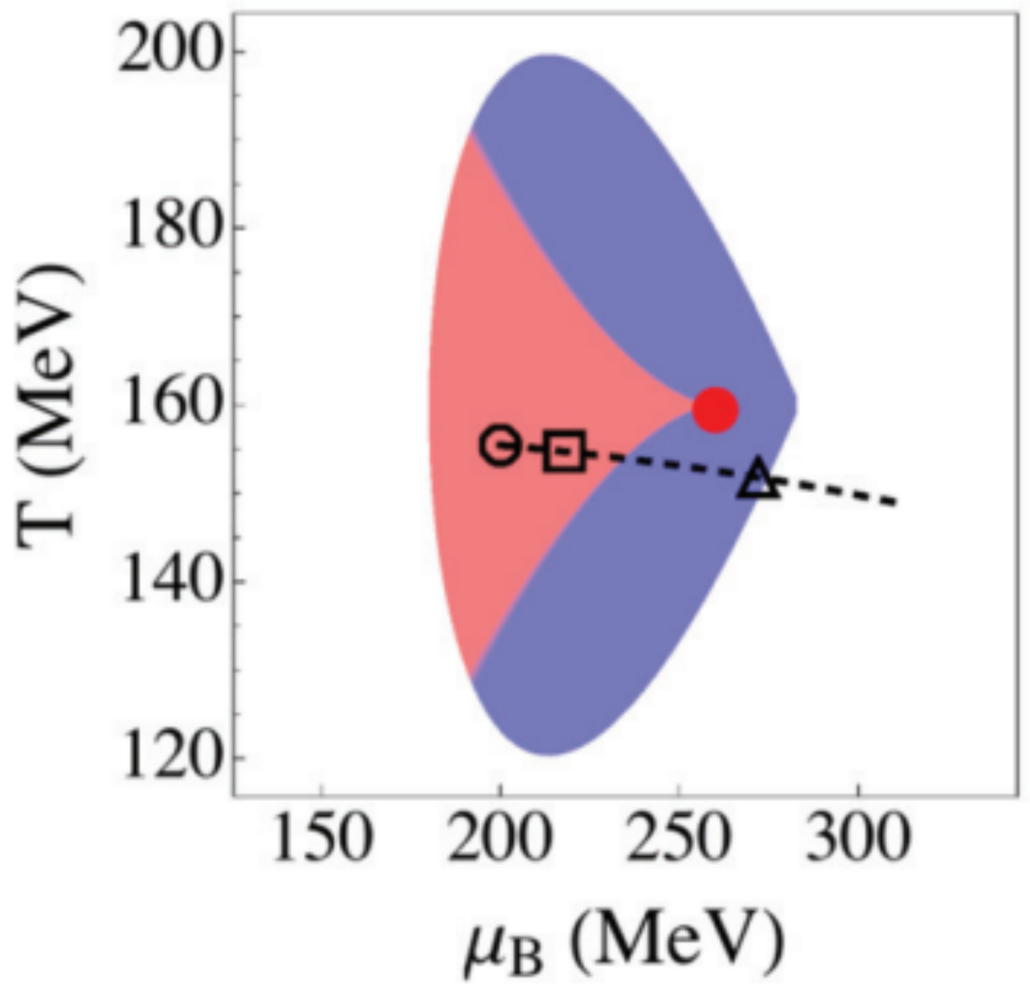


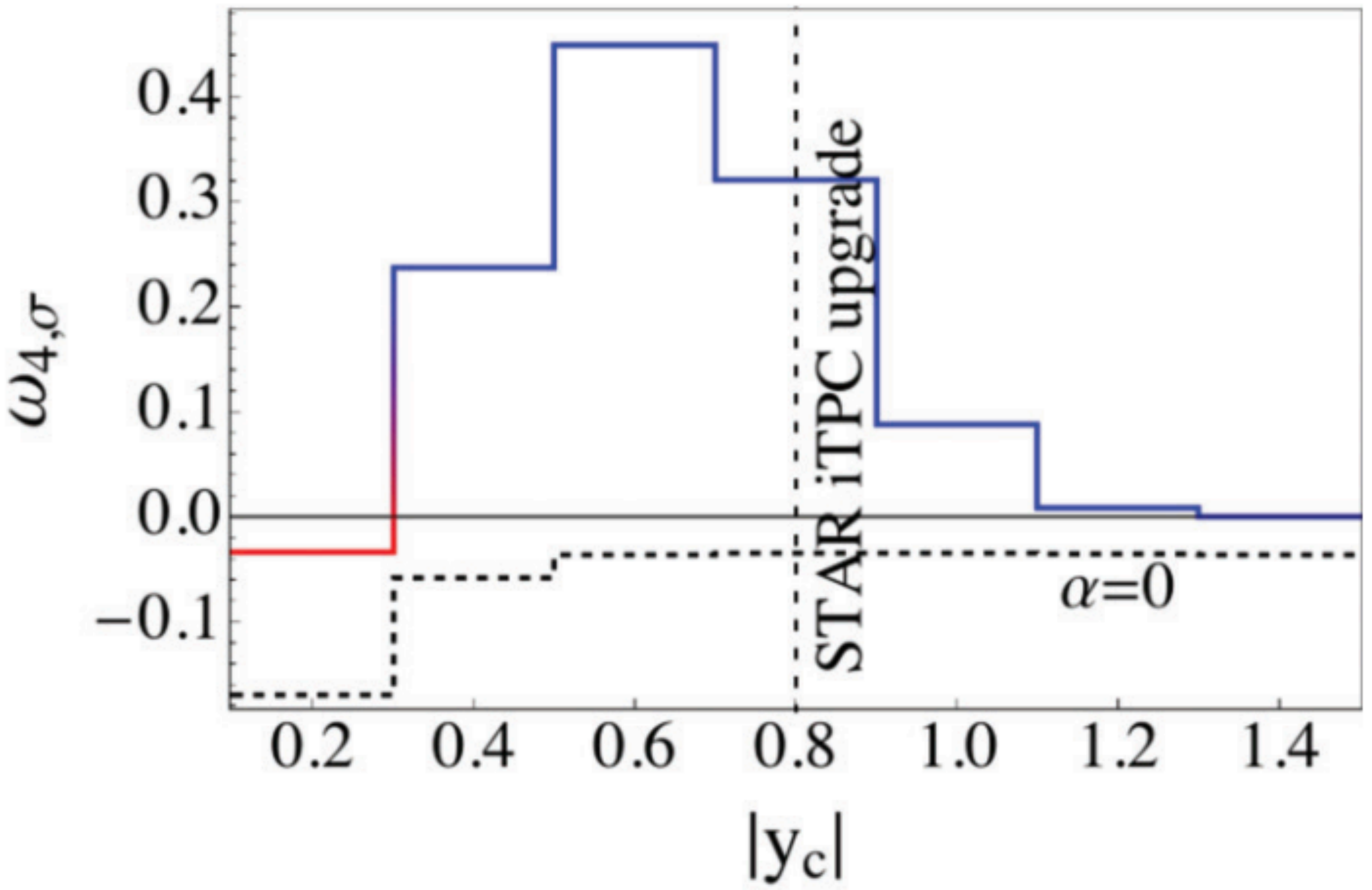
Non-monotonicity



M. A. Stephanov, *Phys. Rev. Lett. 102, 032301*
M. A. Stephanov, *Phys. Rev. Lett. 107, 052301*

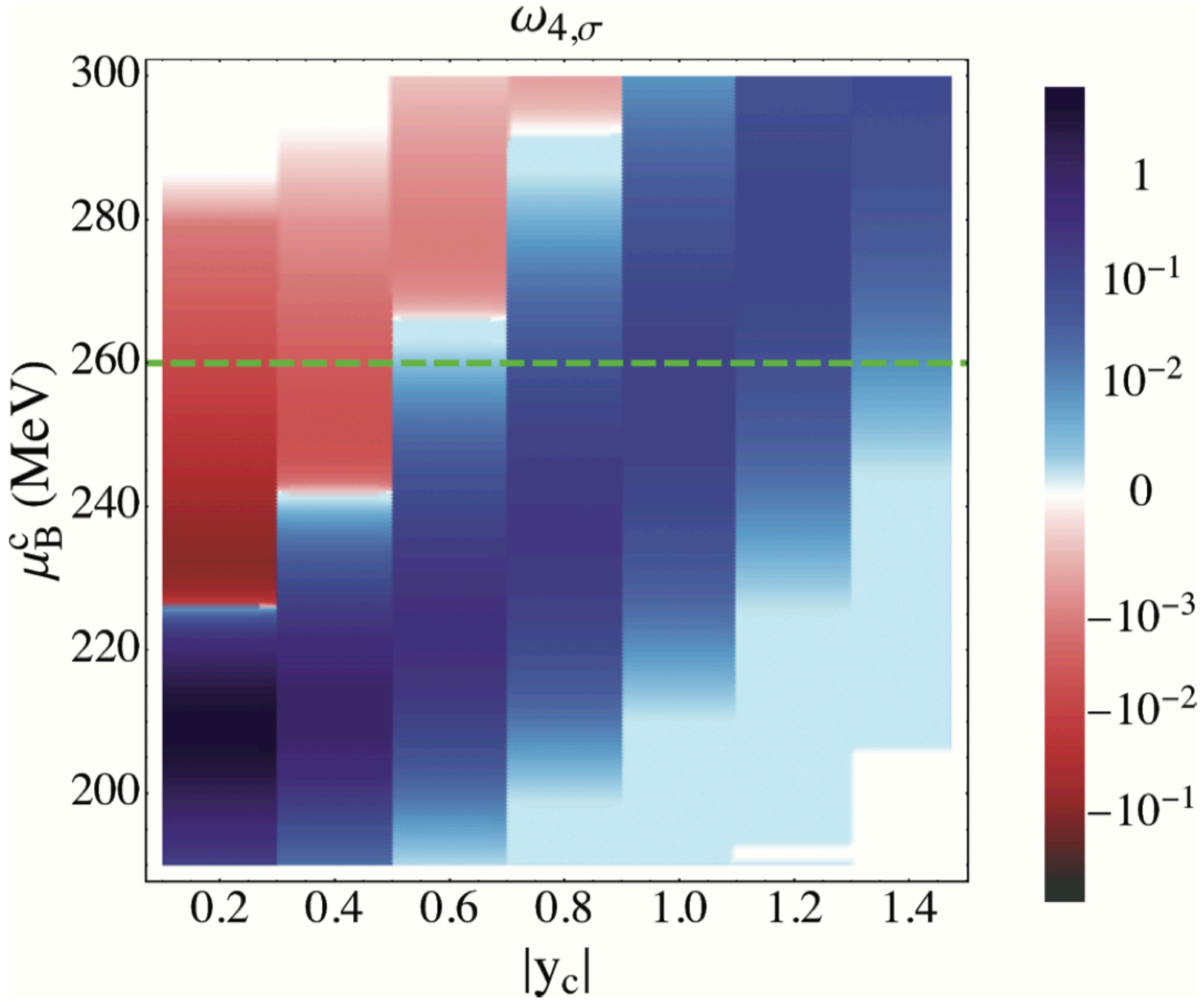
Rapidity scan





Rapidity scan based on 3D Ising model

J. Brewer, S. Mukherjee, K. Rajagopal, and Y. Yin, *Phys. Rev. C 98, 061901(R)*



Rapidity scan can search for CEP in detail.

Particles radiated from an inhomogeneous fireball

Framework of rapidity scan based on continuous-source model

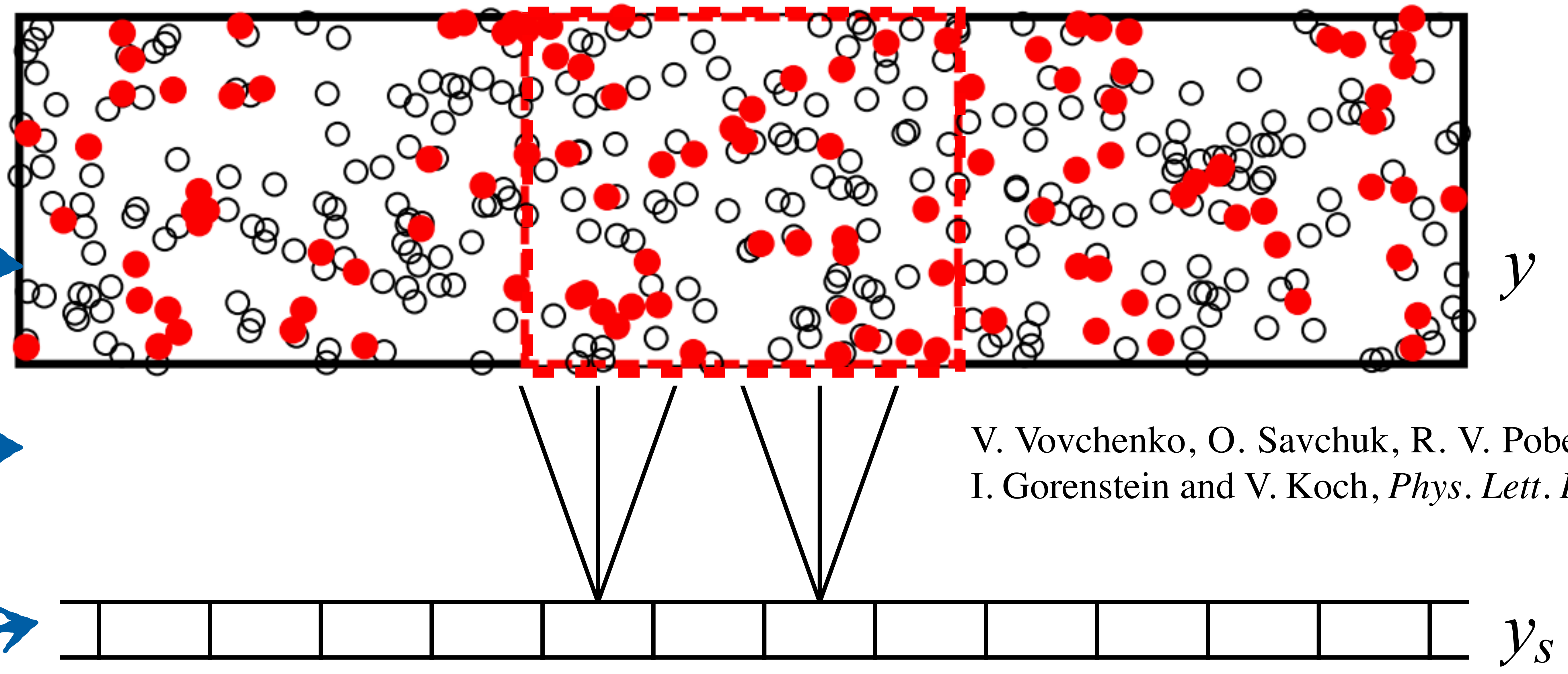
Net-baryon B global conservation
(Canonical Ensemble)

+

Thermal Smearing

+

Inhomogeneous & independent
thermal sources



V. Vovchenko, O. Savchuk, R. V. Poberezhnyuk, M. I. Gorenstein and V. Koch, *Phys. Lett. B 811, 135868*

B_A = Number of ● − ○ in acceptance

"...the net baryon number fluctuates due to the finite acceptance."

P. Braun-Munzinger, B. Friman, K. Redlich, A. Rustamov and J. Stachel, *Nucl. Phys. A 1008, 122141*

Cumulant generating function in finite acceptance range

Cumulant generating function

$$
\boxed{\begin{aligned} g_B(t) &= \frac{B}{2}\ln\left[\frac{q_1(t)}{q_2(t)}\right] \\ &+\ln\left\{I_B\left[2\sqrt{\mathcal{Z}\bar{\mathcal{Z}}}\sqrt{q_1(t)\,q_2(t)}\right]\right\}\end{aligned}}
$$

JL, L. Du and S. Shi, *Phys. Rev. C* **109**, 034907(2024)

$$q_1(t) = 1 + \alpha_B + \alpha_B e^{t}$$

$$q_2(t) = 1 + \alpha_{\bar{B}} + \alpha_{\bar{B}} e^{-t}$$

$$\mathcal{Z} = \langle N_B \rangle$$

$$\bar{\mathcal{Z}} = \langle N_{\bar{B}} \rangle$$

$$\longrightarrow \quad \kappa_n^B = \left.\frac{\partial^n g_B(t)}{\partial t^n}\right|_{t=0} \quad \longrightarrow$$

The 1st to 6th cumulants

$$\kappa_1^B = \langle B_A \rangle$$

$$\kappa_2^B = \left\langle (\delta B_A)^2 \right\rangle$$

$$\kappa_3^B = \left\langle (\delta B_A)^3 \right\rangle$$

$$\kappa_4^B = \left\langle (\delta B_A)^4 \right\rangle - 3\left\langle (\delta B_A)^2 \right\rangle^2$$

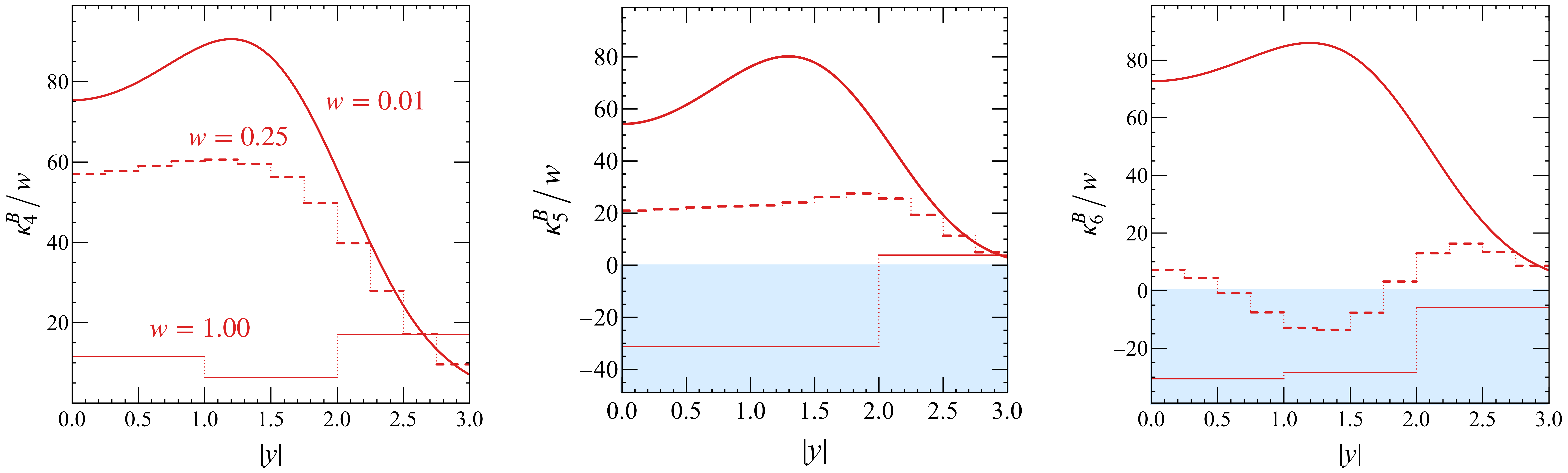
$$\kappa_5^B = \left\langle (\delta B_A)^5 \right\rangle - 10\left\langle (\delta B_A)^3 \right\rangle\left\langle (\delta B_A)^2 \right\rangle$$

$$\begin{aligned}\kappa_6^B = &\left\langle (\delta B_A)^6 \right\rangle - 15\left\langle (\delta B_A)^4 \right\rangle\left\langle (\delta B_A)^2 \right\rangle \\ &-10\left\langle (\delta B_A)^3 \right\rangle^2 + 30\left\langle (\delta B_A)^2 \right\rangle^3\end{aligned}$$

$$\delta B_A = B_A - \langle B_A \rangle$$

X. Luo and N. Xu, *Nucl. Sci. Tech. 28, 112*

Cumulants of Au + Au @ 19.6 GeV in rapidity scan



The 4th to 6th cumulants in rapidity scan

"… five and six…show a difference in sign."

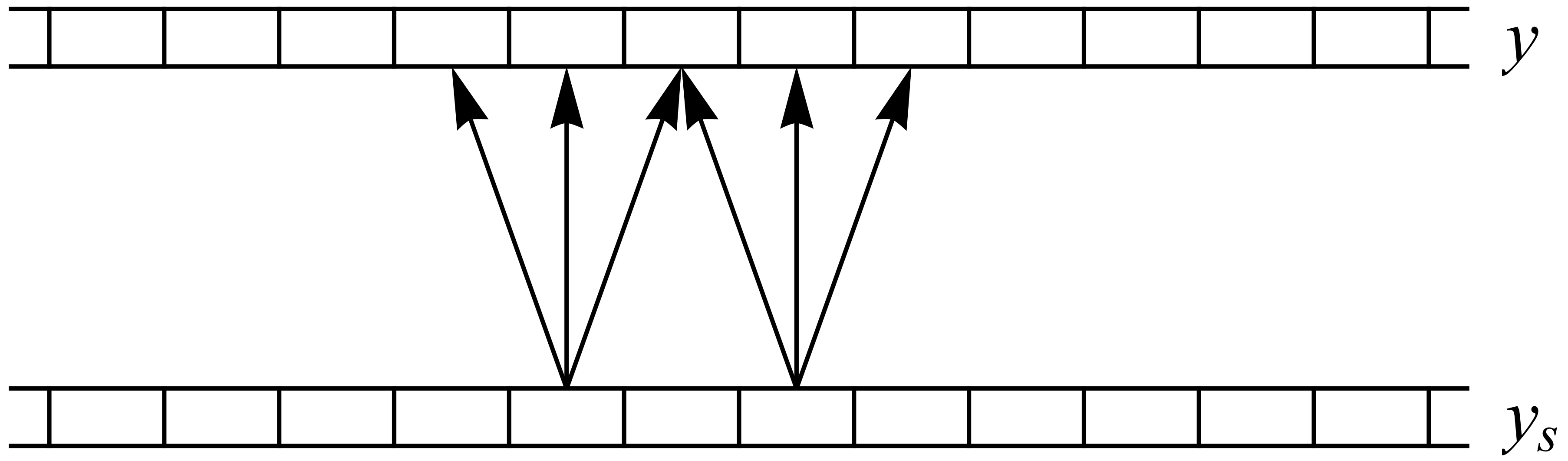
STAR Collaboration, *Phys. Rev. Lett. 130, 082301*

Thermodynamic variables on QCD phase diagram

$$\kappa_B^n = \left.\frac{\partial^n g_B(t)}{\partial t^n}\right|_{t=0}$$

$$g_B(t) = \frac{B}{2}\ln\left[\frac{q_1(t)}{q_2(t)}\right] + \ln\left\{I_B\left[2\sqrt{\mathcal{Z}\bar{\mathcal{Z}}}\sqrt{q_1(t)\,q_2(t)}\right]\right\}$$

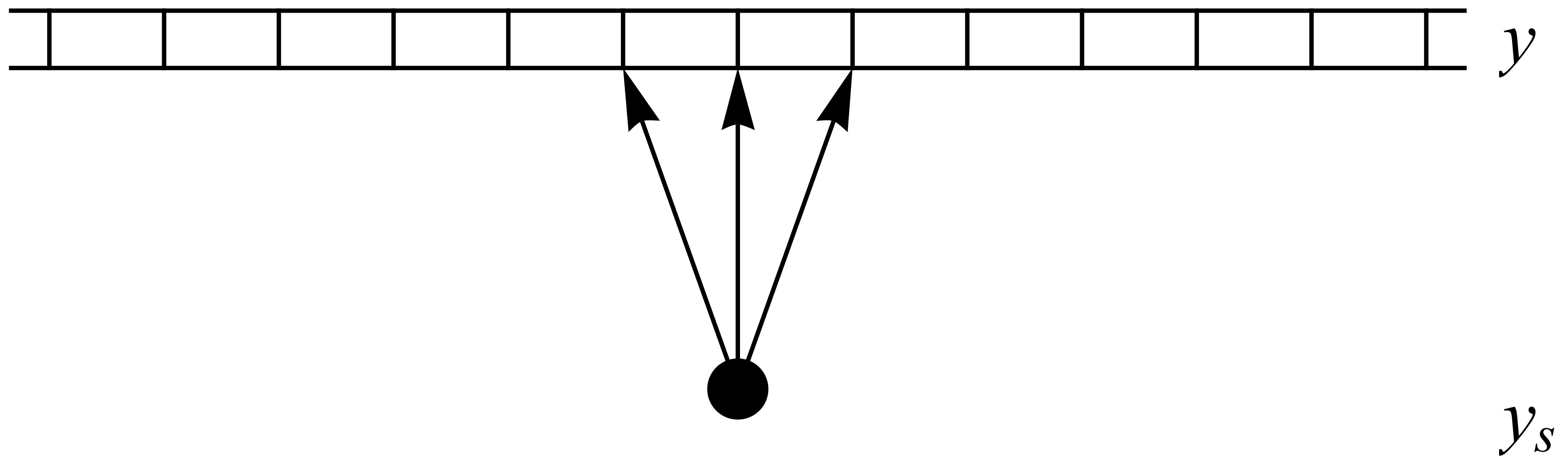
JL, L. Du and S. Shi, PRC **109** 034907



Inhomogeneous fireball

$$g_B(t) = \frac{B}{2}\ln\left[\frac{q_1(t)}{q_2(t)}\right] + \ln\left\{I_B\left[2Z\sqrt{q_1(t)\,q_2(t)}\right]\right\}$$

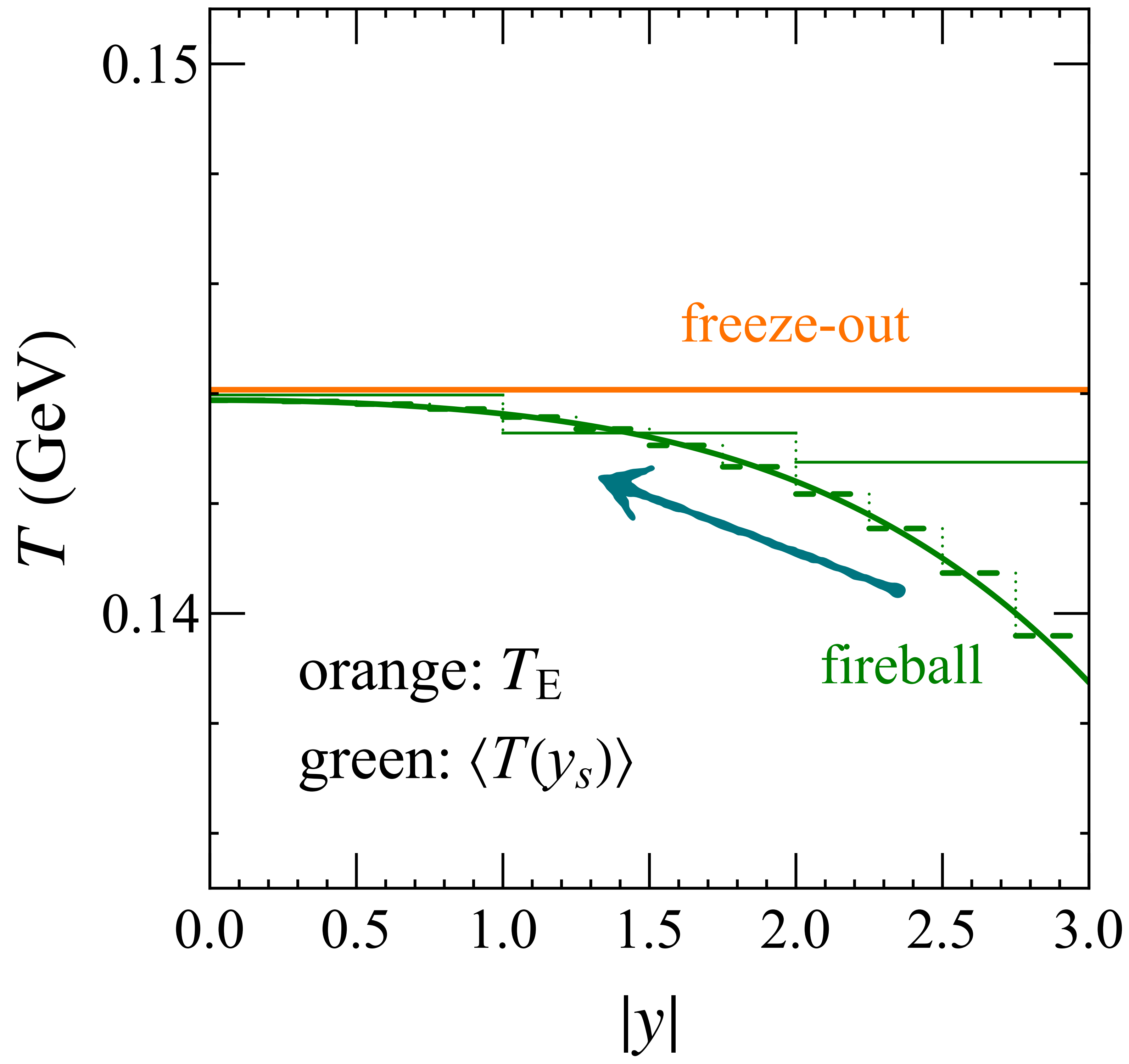
Nucl.Phys.A 1008, 122141

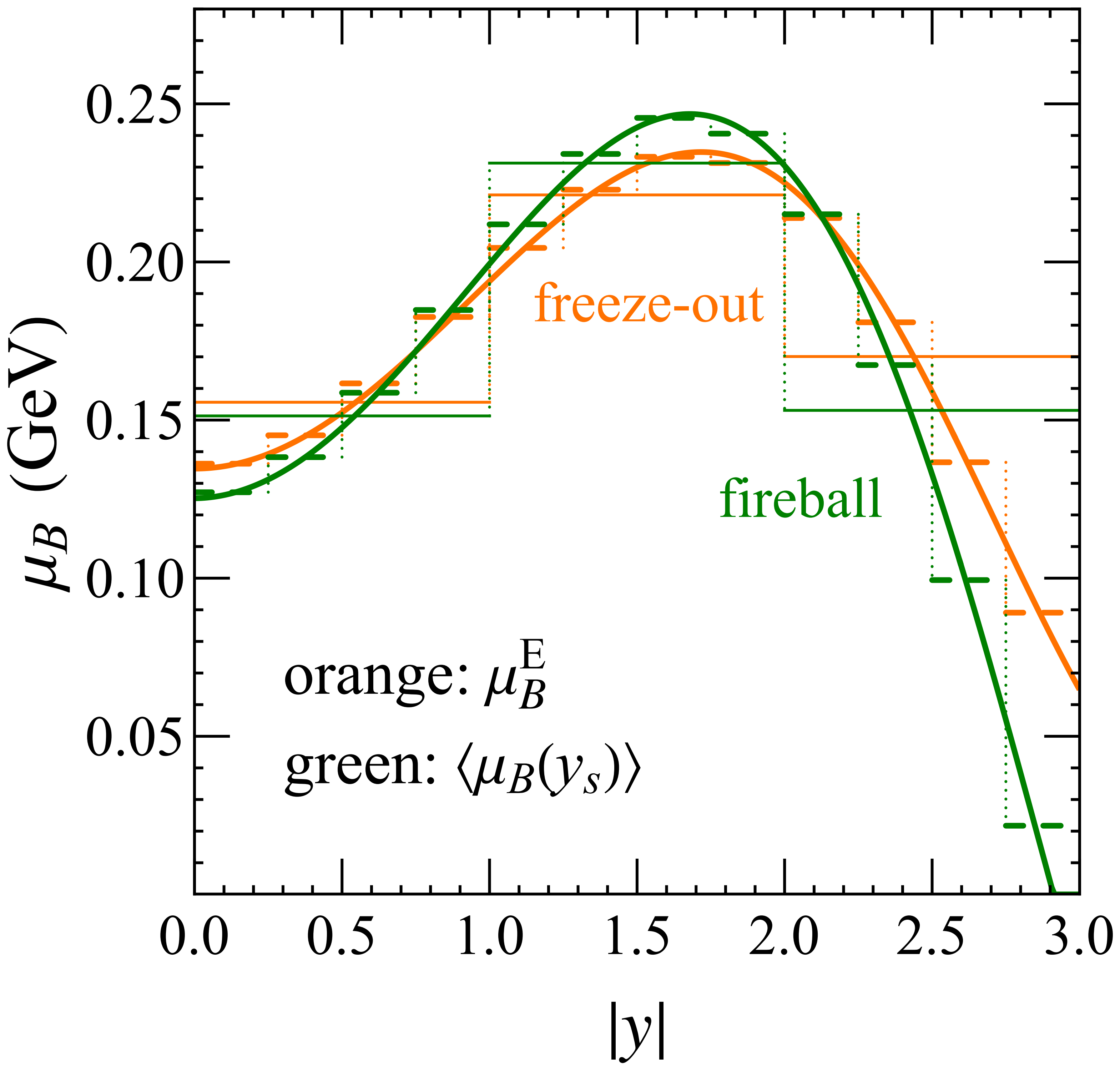


Point on QCD phase diagram

The same (anti-)baryon acceptance + $\mathcal{Z}\bar{\mathcal{Z}} = Z^2$

Thermodynamic variables on QCD phase diagram

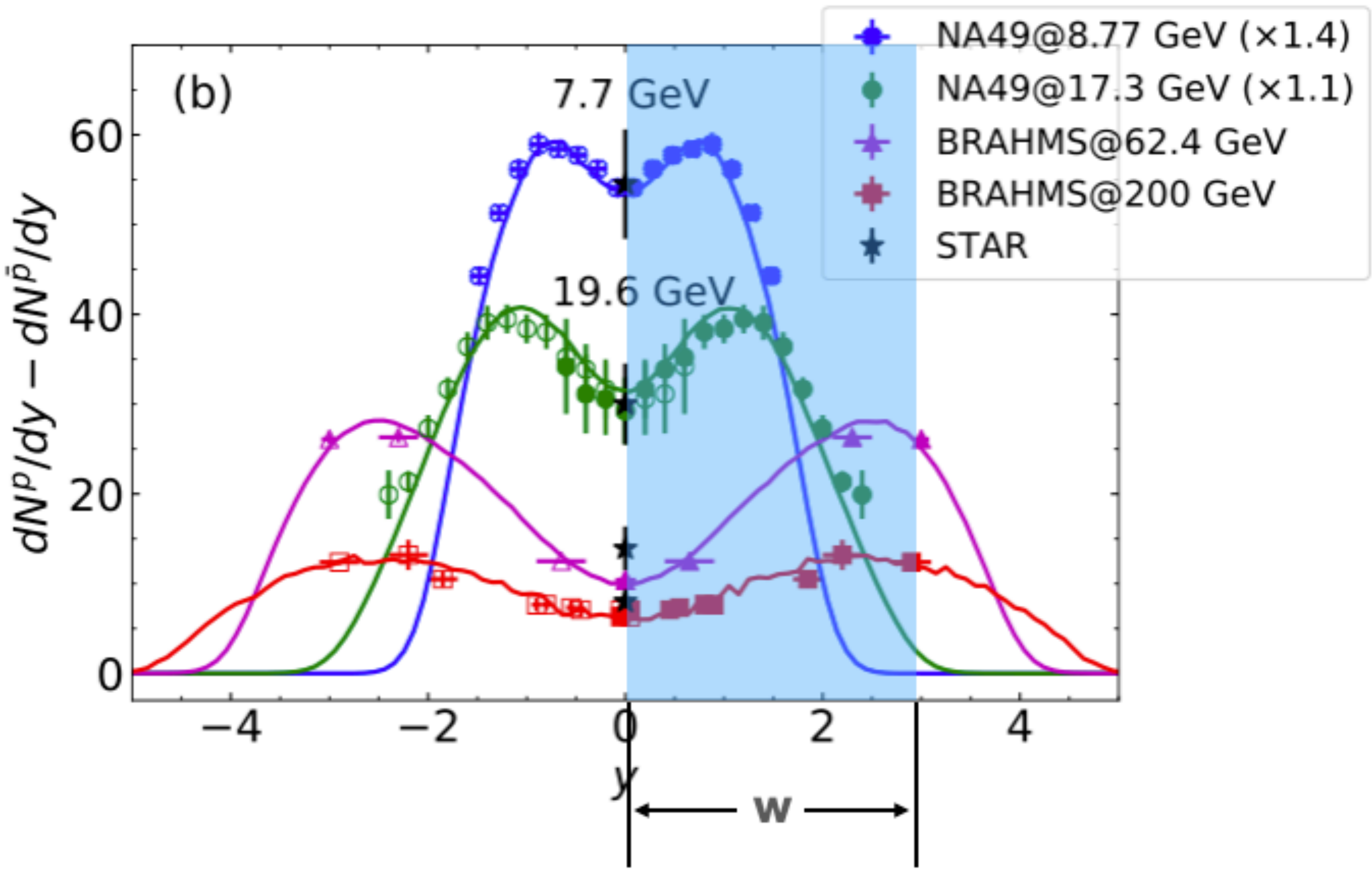




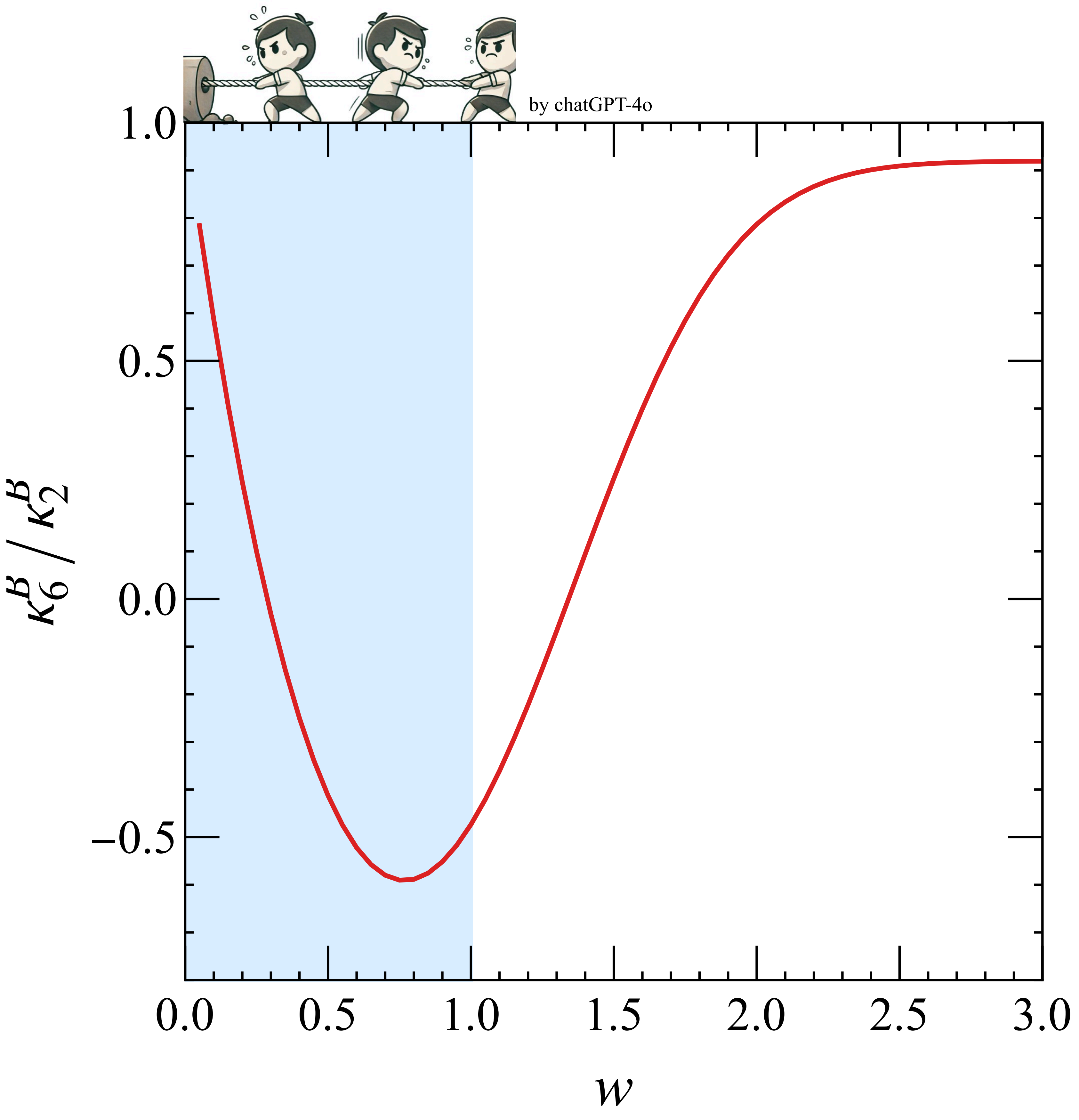
T_{E} & μ_{E}: Extracted variables at chemical freeze-out

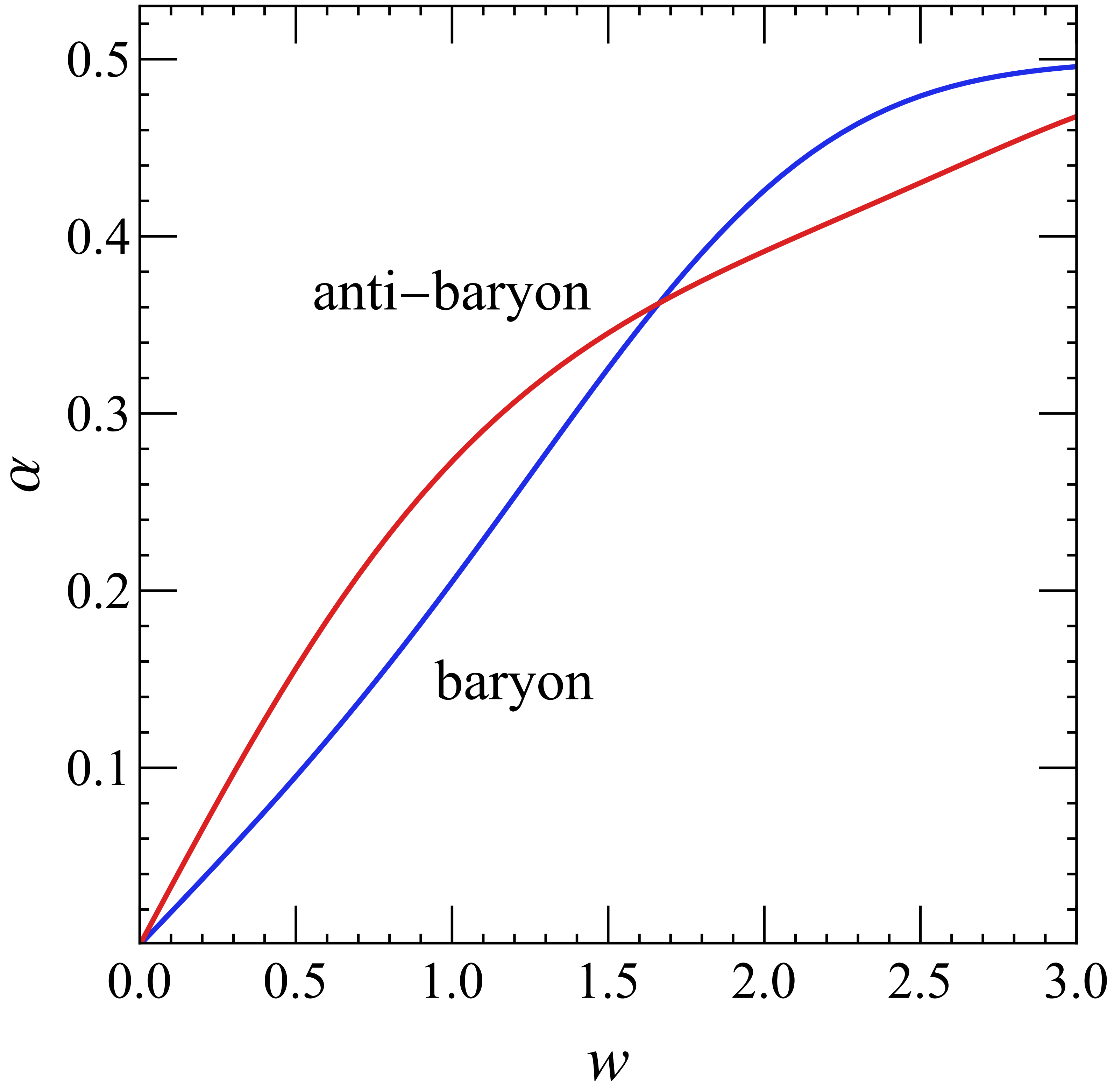
$\langle T(y_s)\rangle$ & $\langle \mu_B(y_s)\rangle$: Averaged variables of inhomogeneous fireball

Conservation v.s. Critical



Conservation v.s. Critical





Non-monotonicity induced by more particles accepted.

Summary & Outlook

Summary

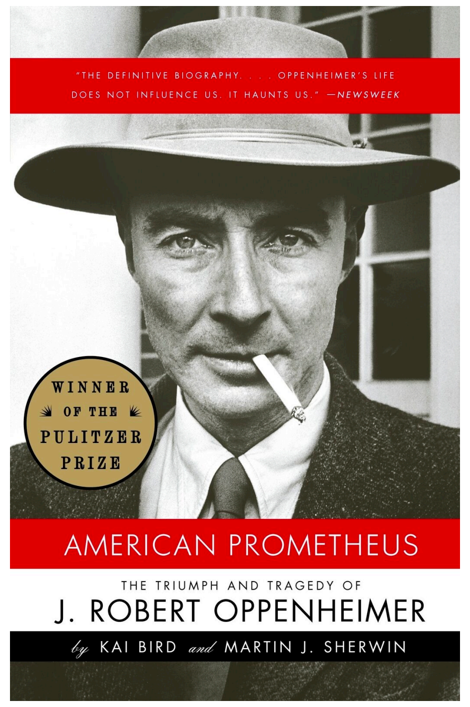
- We derive the expression for net-baryon cumulants generating function within finite rapidity ranges in CE
- Kinematic acceptances may significantly affect high-order cumulants
- Rapidity scan can help us to study intermediate energy collision in detail

Outlook

- A more complete baseline: baryon stopping, volume fluctuation, feed-down…
- Non-equilibrium effect: Hydro+, fluctuations correlations…
- We are working on the signal for separating conservation from critical behavior

… interesting to see…offequilibrium scaling… in ‘rapidity scan

Y. Yin, arXiv: 1811.06519

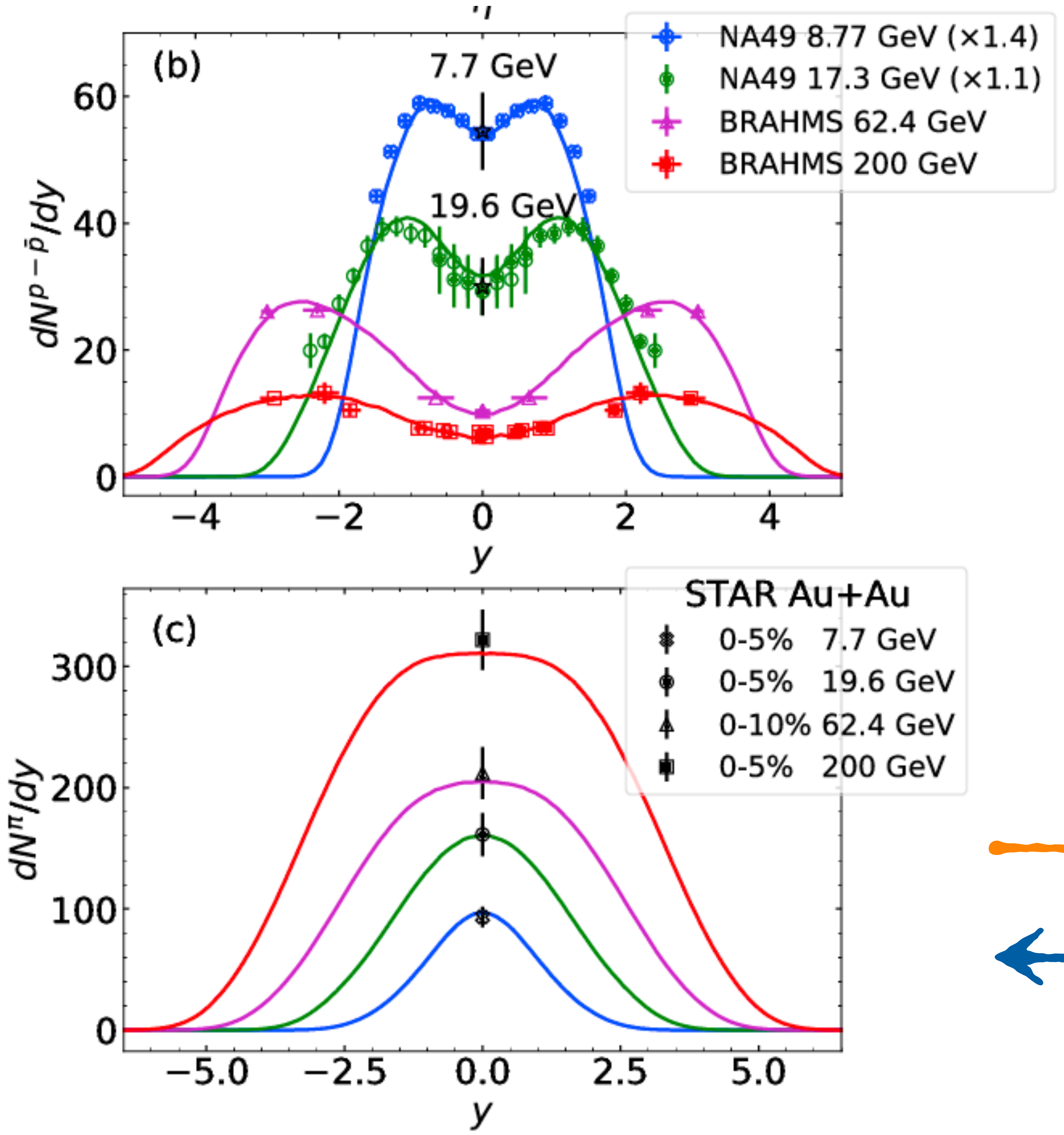


"We cannot know, as a matter of principle, the present in all its details."

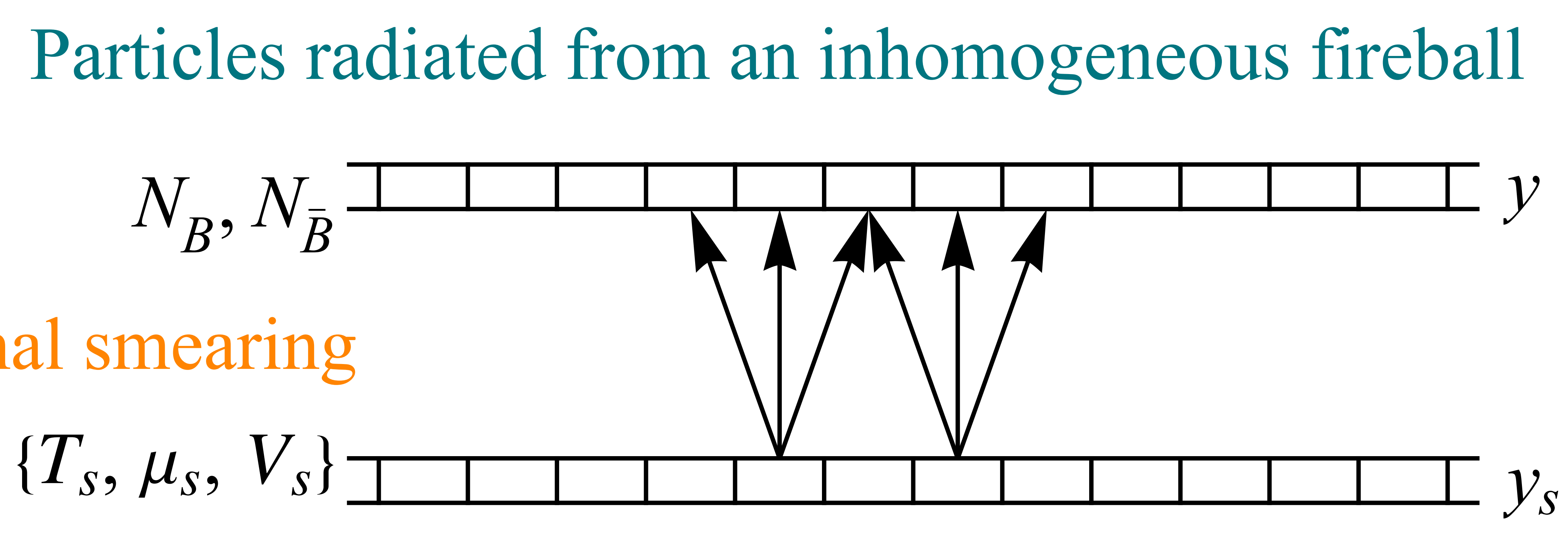
Thanks~

Back Up

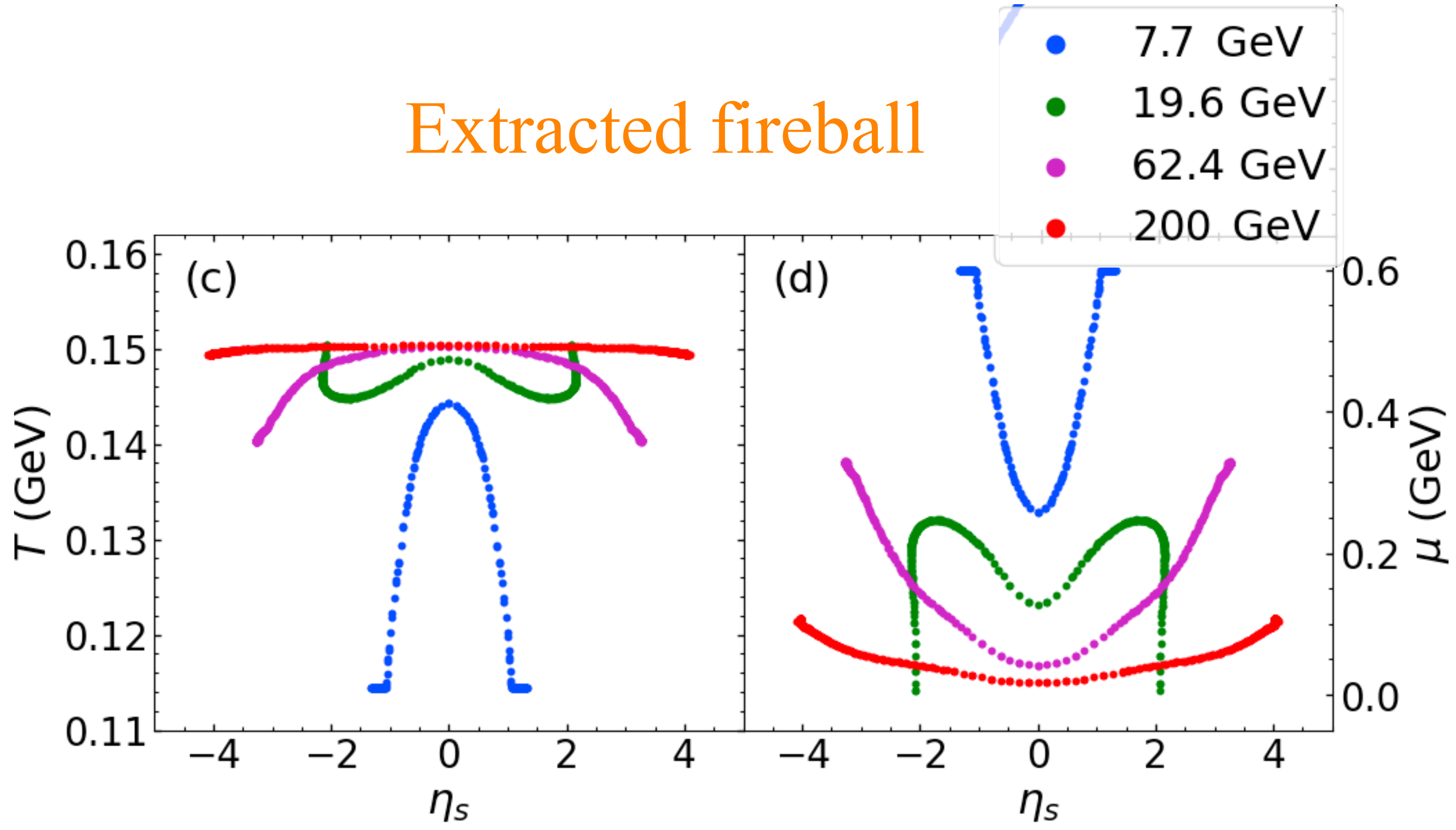
Particles radiated from an inhomogeneous fireball



L. Du, H. Gao, S. Jeon and C. Gale, *Phys. Rev. C* 109, 1

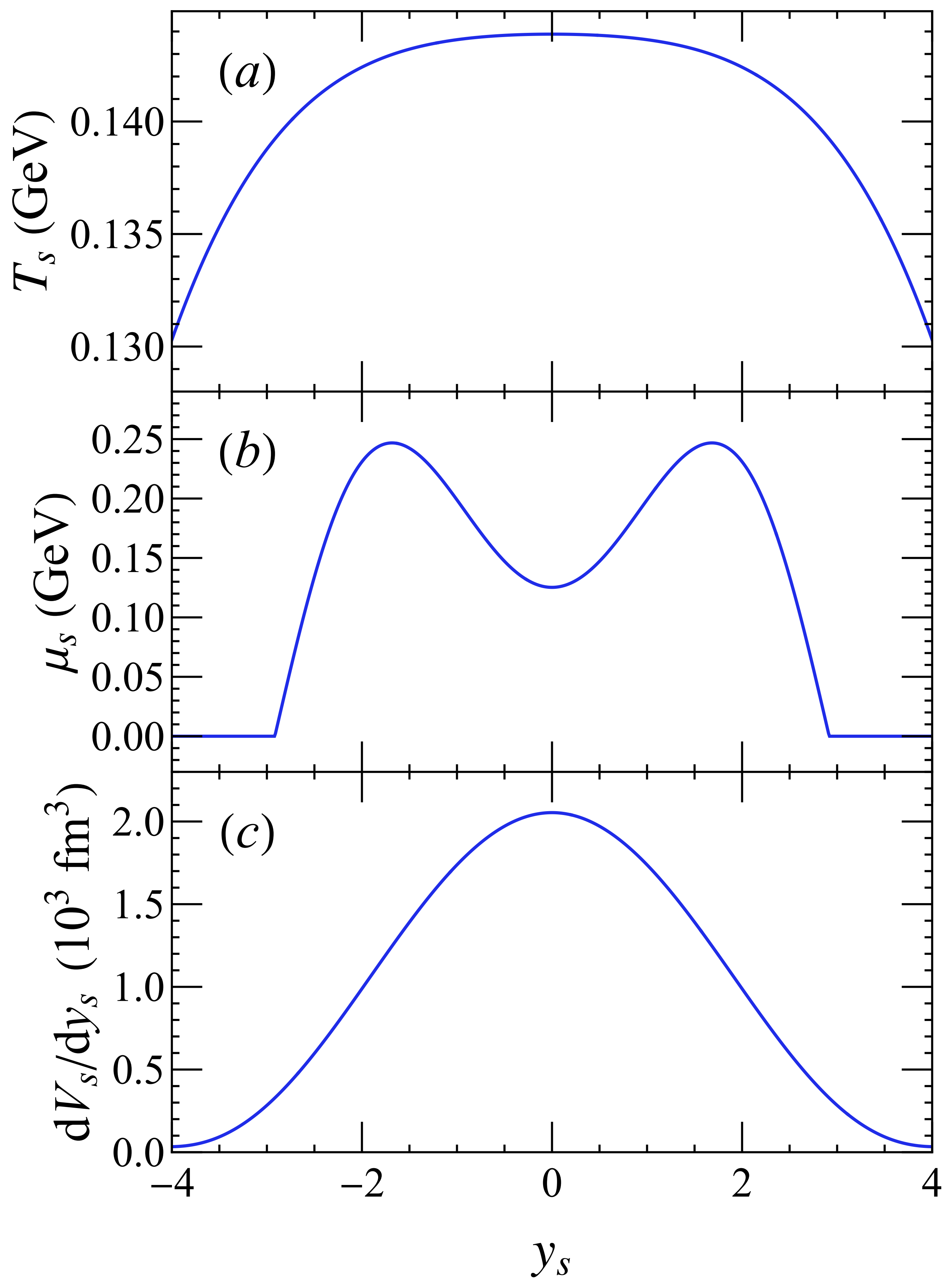


Extracted fireball



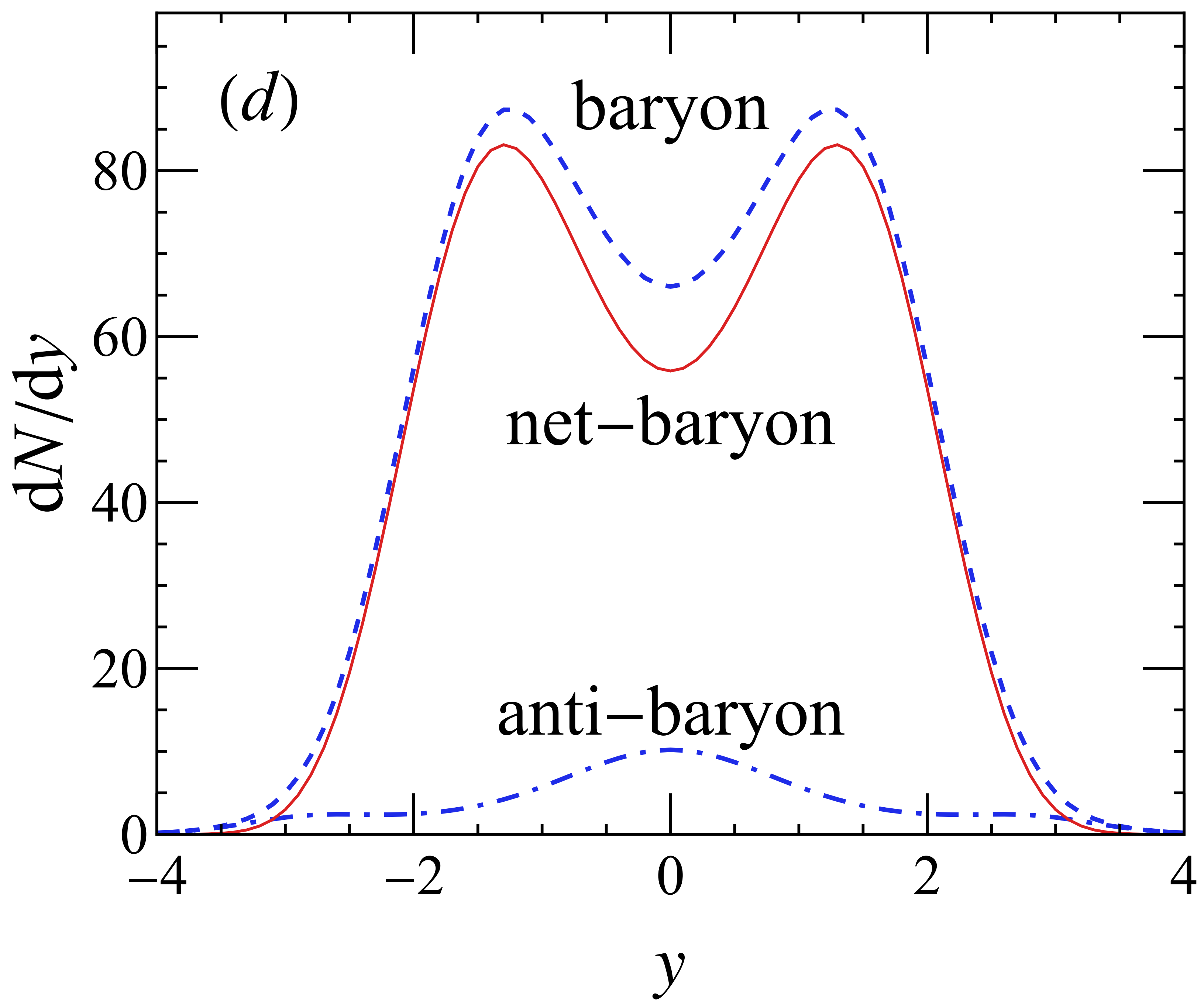
(Anti-)baryons yields in Au + Au @ 19.6 GeV

Inhomogeneous fireball



L. Du, H. Gao, S. Jeon and C. Gale,
Phys. Rev. C 109, 1

Particle yields



Acceptance