Quark Matter 2022, Krakow, Poland (hybrid), Apr. 6, 2022

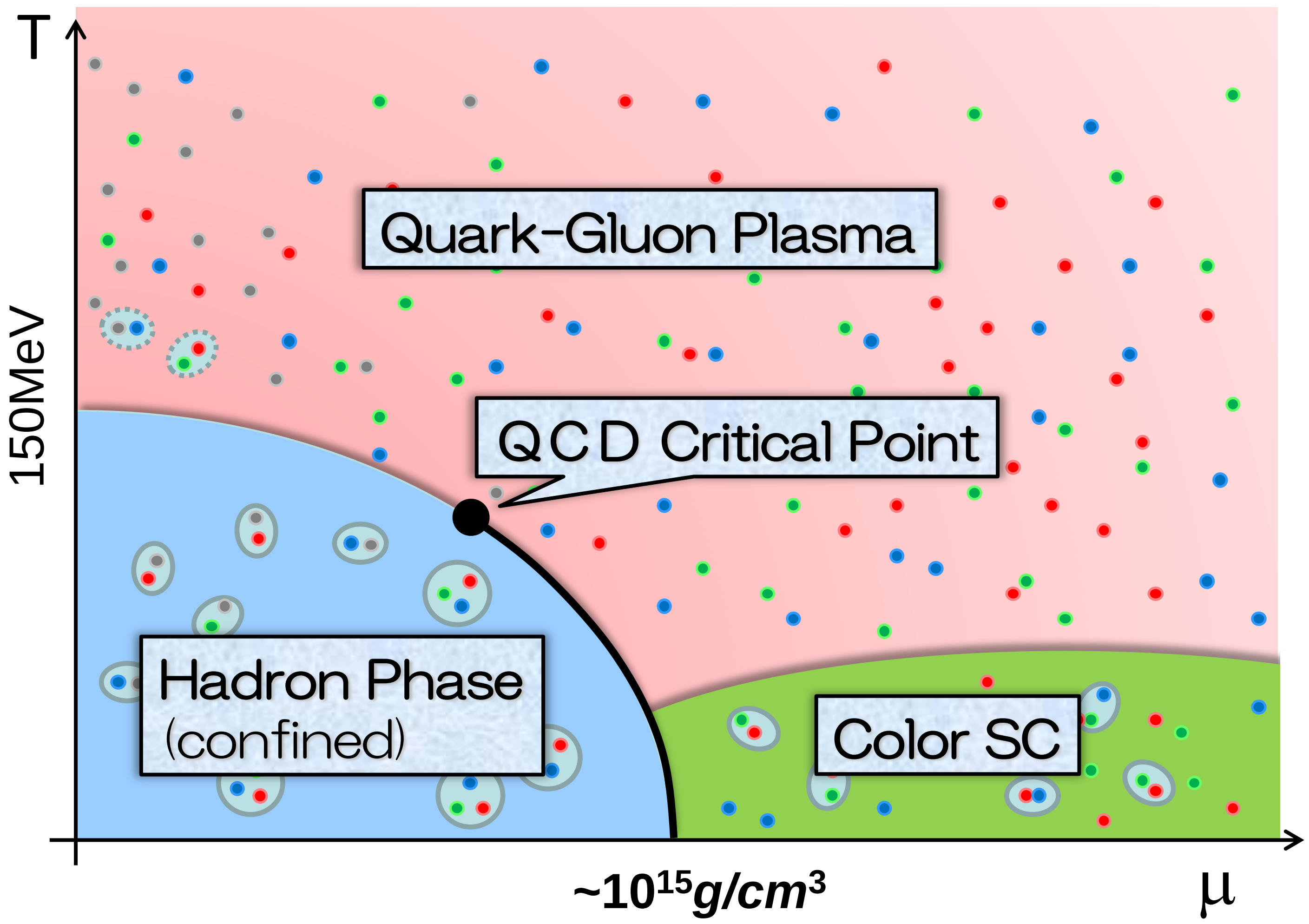
Baryon/Charge Cumulant Ratio at Second Order

Masakiyo Kitazawa (Osaka U.)

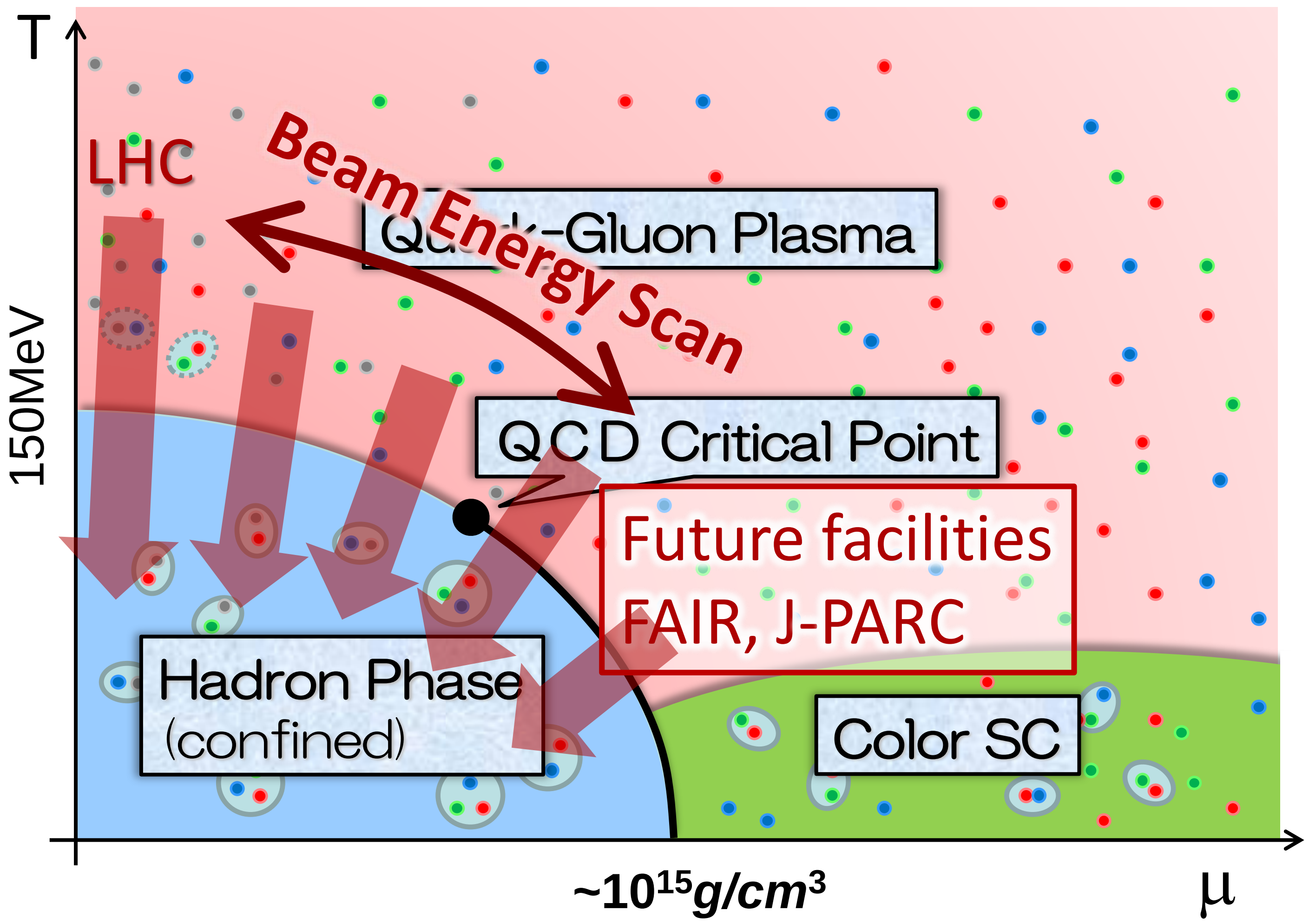
MK, S. Esumi, T. Nonaka, arXiv:2204.#####

MK, EMMI-RRTF, Apr. 2019, GSI; On-line seminar series on RHIC-BES, Sep. 2020

Beam-Energy Scan



Beam-Energy Scan



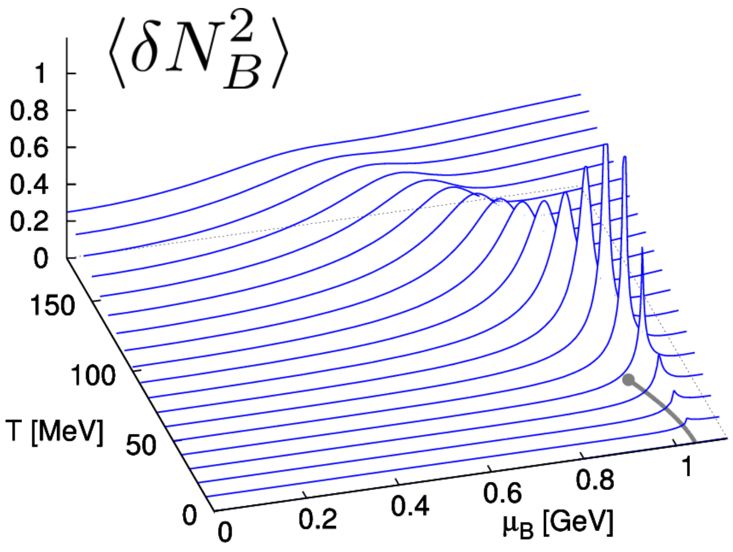
Experiments

- ☐ RHIC-BES
- ☐ HADES
- ☐ NA60
- ☐ FAIR
- ☐ NICA
- ☐ J-PARC-HI
- ☐ …

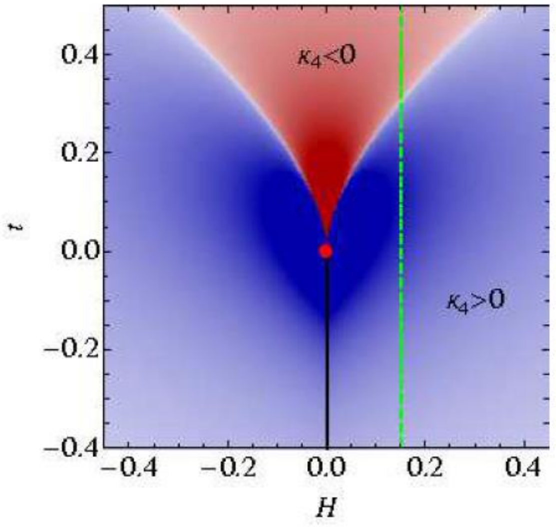
Fluctuations, Cumulants of Conserved Charges

$$\langle N^m \rangle_c = \chi_m V$$

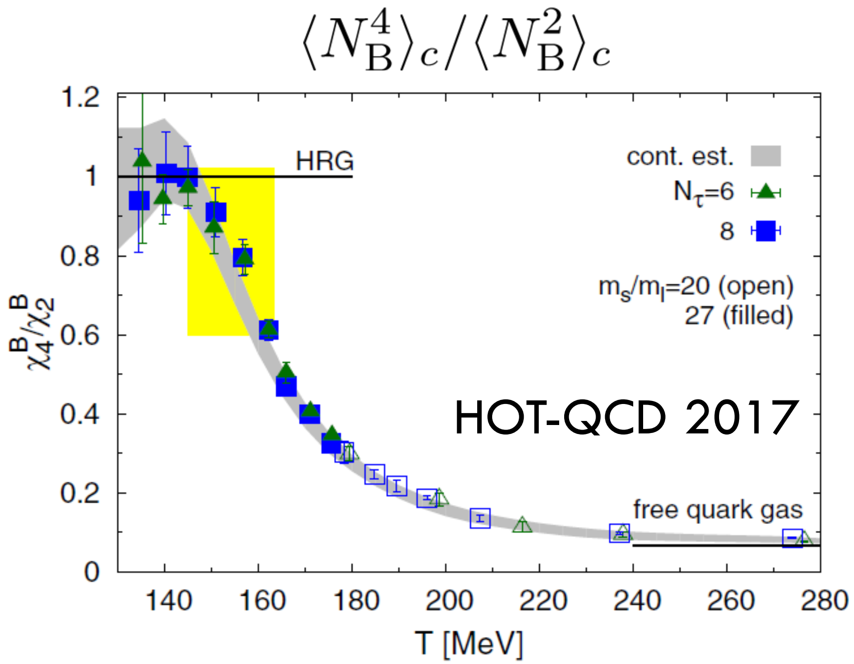
- Divergence and sign change at the QCD-CP. Stephanov,'09; Asakawa, Ejiri, MK,'09
- Volume dependence is canceled out in ratio. Ejiri, Karsch, Redlich,'05
- Direct comparison with lattice QCD simulations.
- Slower diffusion.



Asakawa, Ejiri, MK (2009)



Stephanov (2011)

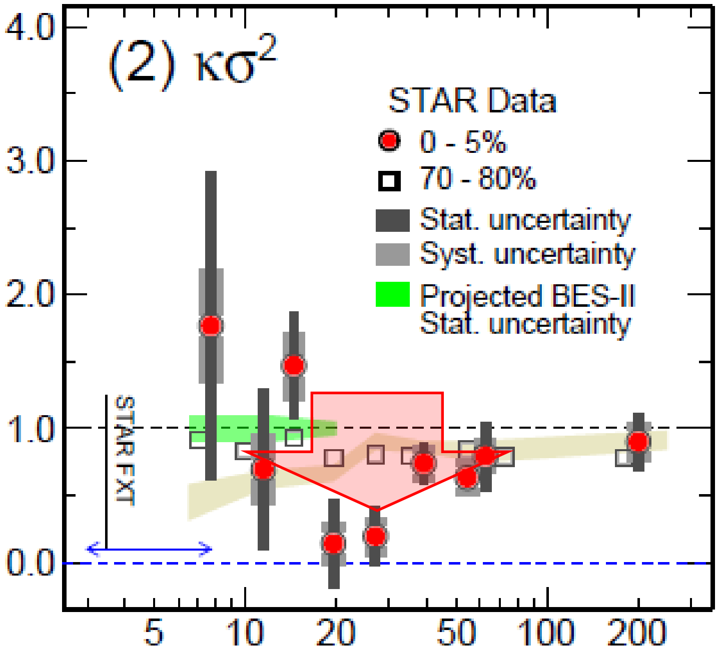


Experimental Results

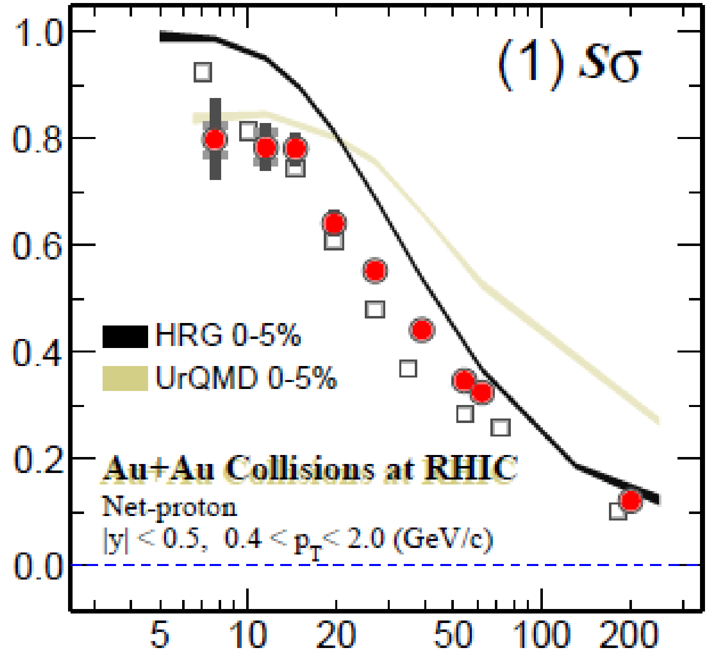
Net-proton number cumulants

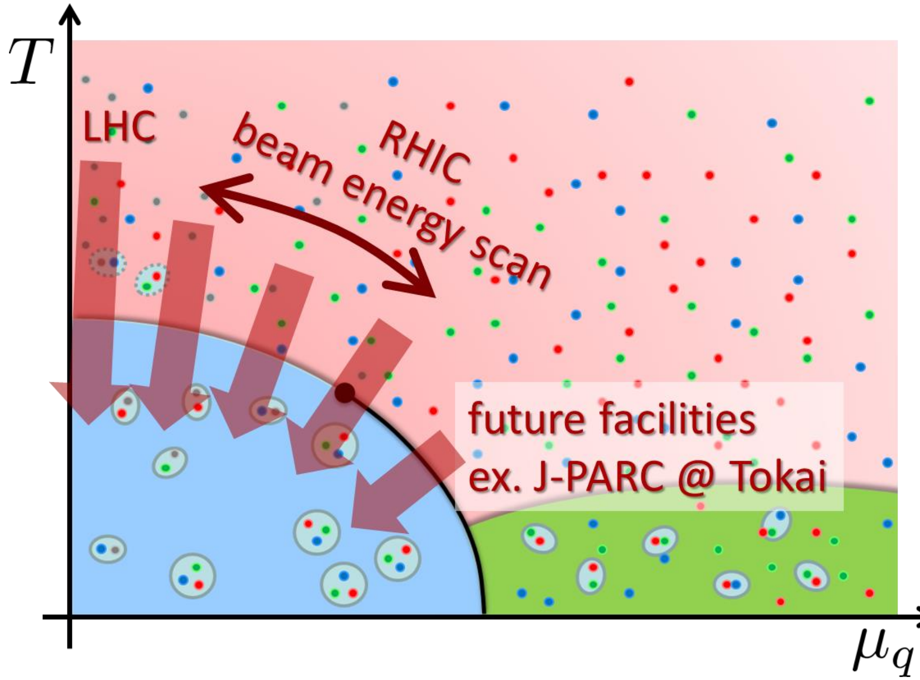
STAR, 2020 (2001.02852)

$\langle N_p^4 \rangle_c / \langle N_p^2 \rangle_c$



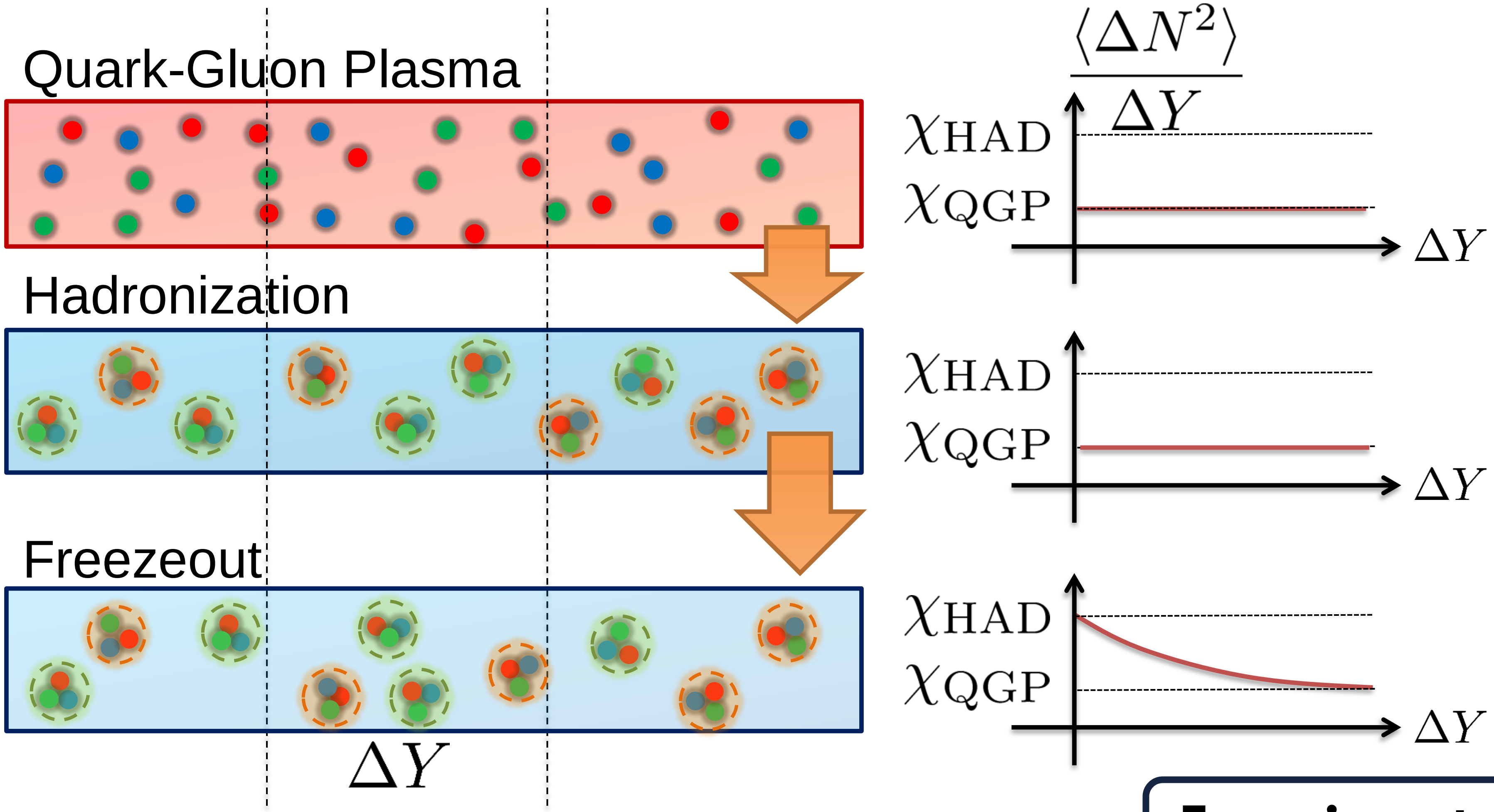
$\langle N_p^3 \rangle_c / \langle N_p^2 \rangle_c$





- ☐ Non-Poisson and non-monotonic behaviors in the ratio of higher order cumulants.
- ☐ When are these fluctuations generated?

Evolution of Conserved-charge Fluctuations



Fluctuations of CC are modified by the diffusion.

Relaxation time becomes longer as ΔY →large.

Experiments on $\langle N_Q^2 \rangle$

- ☐ No QGP signal @ RHIC ('02, '03)
- ☐ QGP signal? @ ALICE ('12)

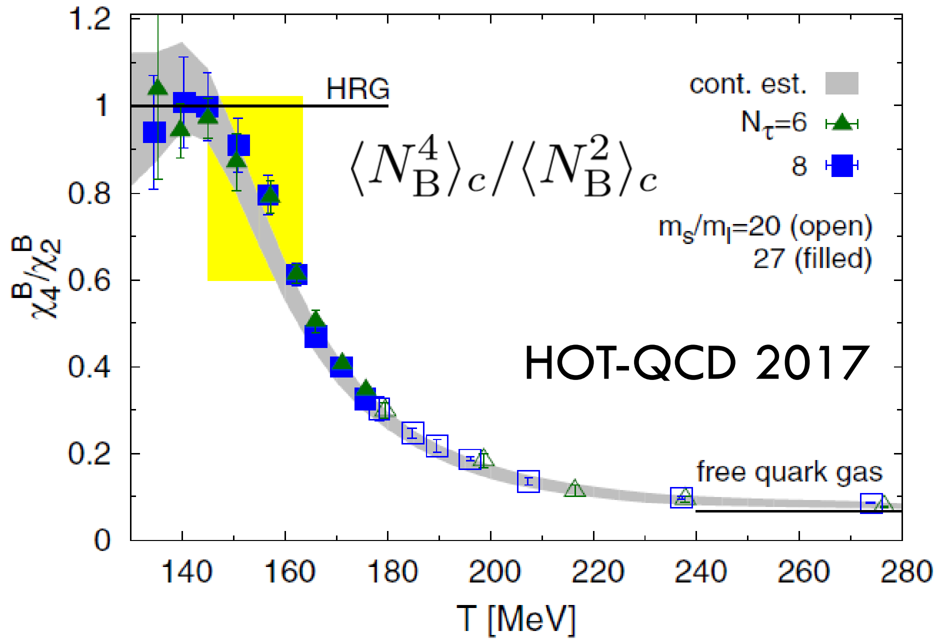
Asakawa, Heinz, Muller, 2000
Jeon, Koch, 2000; Shuryak, Stephanov, 2001

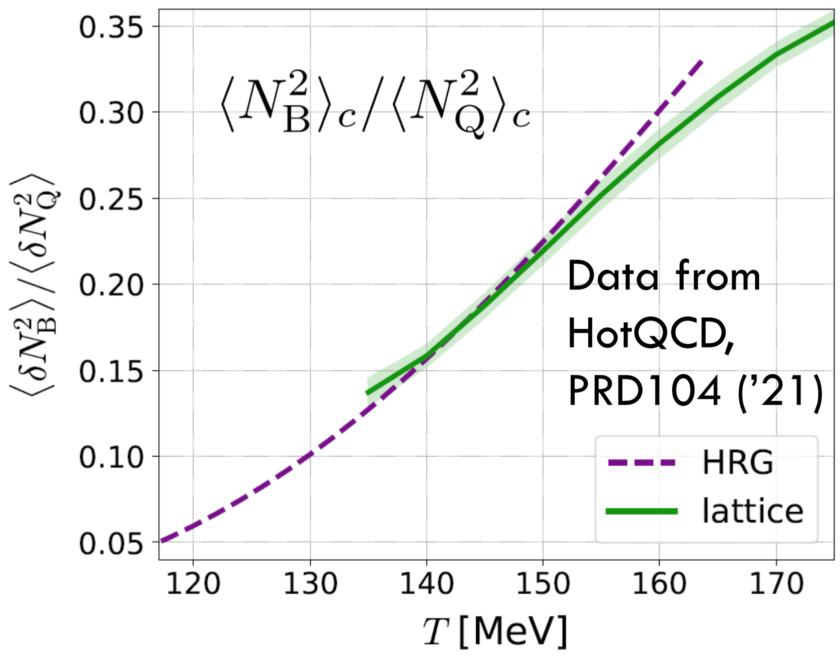
The purpose of this study: $\langle N_B^2 \rangle_c / \langle N_Q^2 \rangle_c$

$\langle N_{\rm B}^2 \rangle_c / \langle N_{\rm Q}^2 \rangle_c$

- Ratio of 2nd order: Suppress uncertainties from various experimental effects compared with higher orders.
- Almost linear T dependence around T_c^*.

- $\sqrt{s_{NN}} = 200\text{GeV}$
- 0-5% centrality
- Δy dependence
- Construction of baryon number, p_T-acceptance correction





Experimental Data

$\langle N_p^2 \rangle_c$

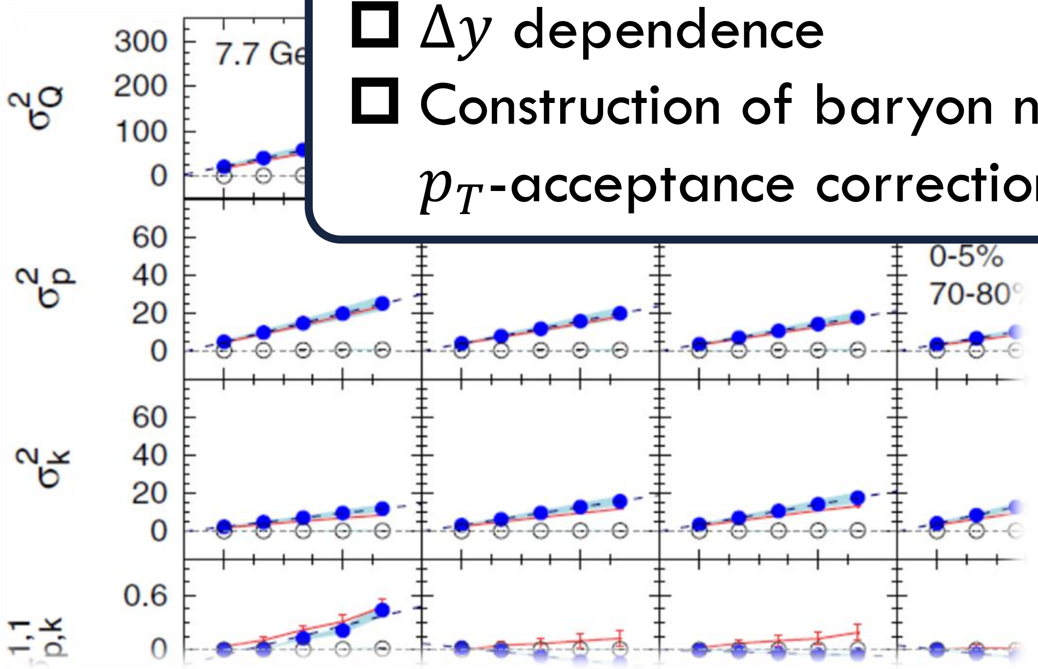
STAR, PRC104,024902 (2021)

- proton cumulants up to 4th order
- **rapidity window** Δy
- $0.4 < p_T < 2.0$GeV/c

$\langle N_{\rm Q}^2 \rangle_c$

STAR, PRC100,014902 (2019)

- 2nd mixed cumulants of p, ,pi, K, Q
- **pseudo-rapidity window** $\Delta\eta$
- $0.4 < p_T < 1.6$GeV/c
- Total charge: private comm. A. Chattergee



- ☐ $\sqrt{s_{NN}} = 200$GeV
- ☐ 0-5% centrality
- ☐ Δy dependence
- ☐ Construction of baryon number, p_T-acceptance correction

- ☐ proton → baryon cumulants MK, Asakawa,'12;'12
- ☐ Rapidity is better than pseudo-rapidity Ohnishi, MK, Asakawa, '16
- ☐ Wider acceptance is more desirable.

p_T-Acceptance Correction

p_T Acceptance

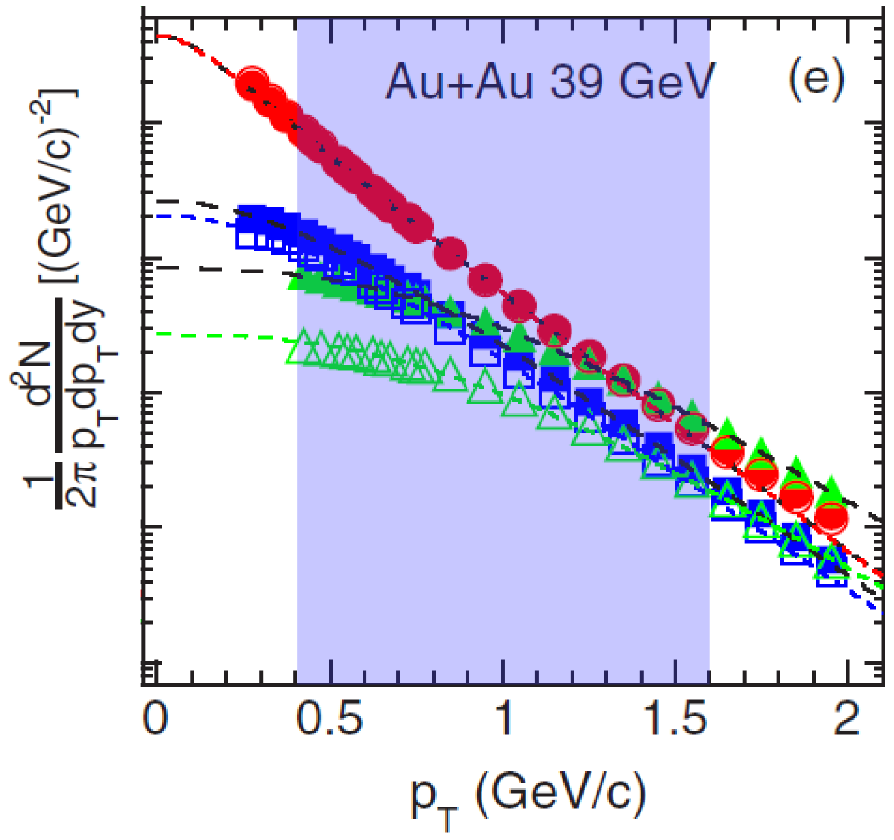
0.4<p_T<1.6 [GeV/c]
PRC100,014902('19)

0.4<p_T<2.0 [GeV/c]
PRC104,024902('21)

Particles in p_T space

- Electric charge: **49%**
- Protons: **82%**

blast wave model @ $\sqrt{s_{NN}}$=200 GeV



Modification by p_T-cut should be corrected.
This study: Binomial distribution model.

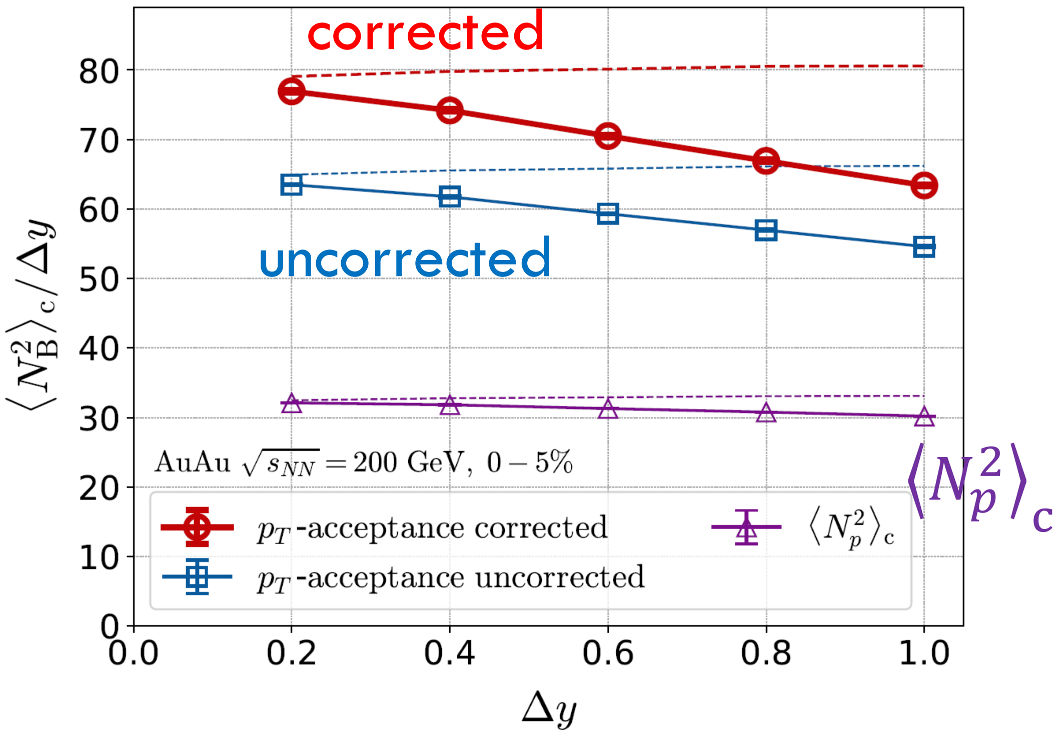
$$\langle N_{\rm net}^2\rangle_c^{\rm corrected} = \frac{1}{p^2}\Big(\langle n_{\rm net}^2\rangle_c - (1-p)\langle n_{\rm tot}\rangle_c\Big)$$

MK, Asakawa, '12, '12

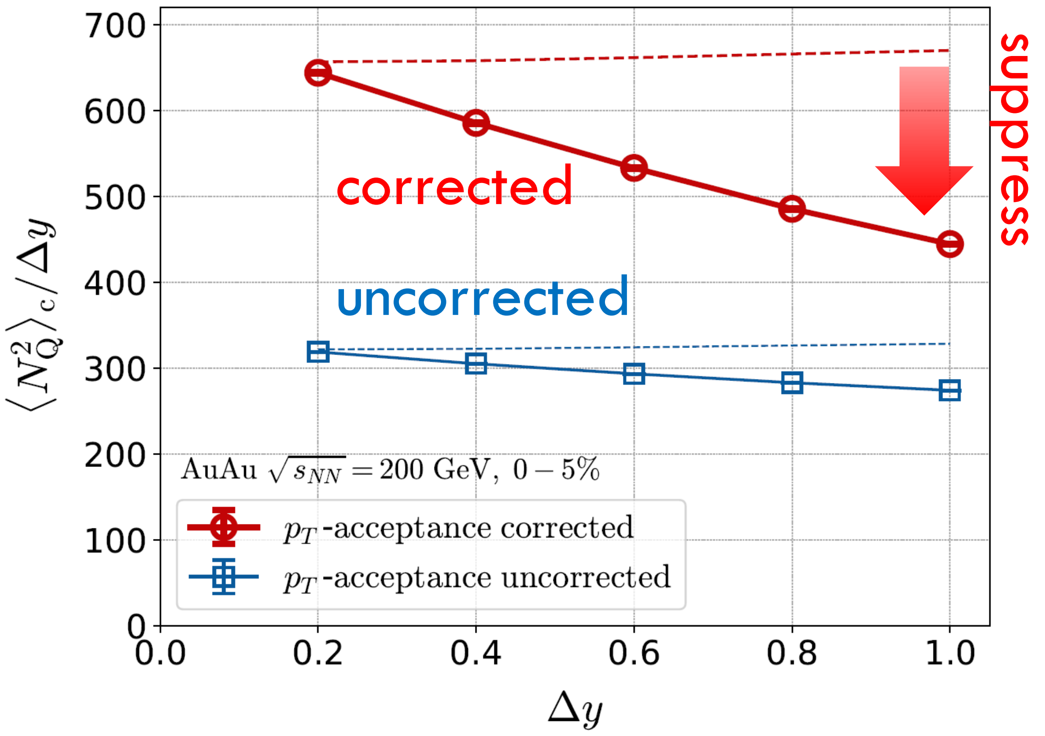
Cumulants: Proton→Baryon & Acceptance Correction

Data from STAR, '19, '21

$\langle N_B^2 \rangle_c / \Delta y$



$\langle N_Q^2 \rangle_c / \Delta y$



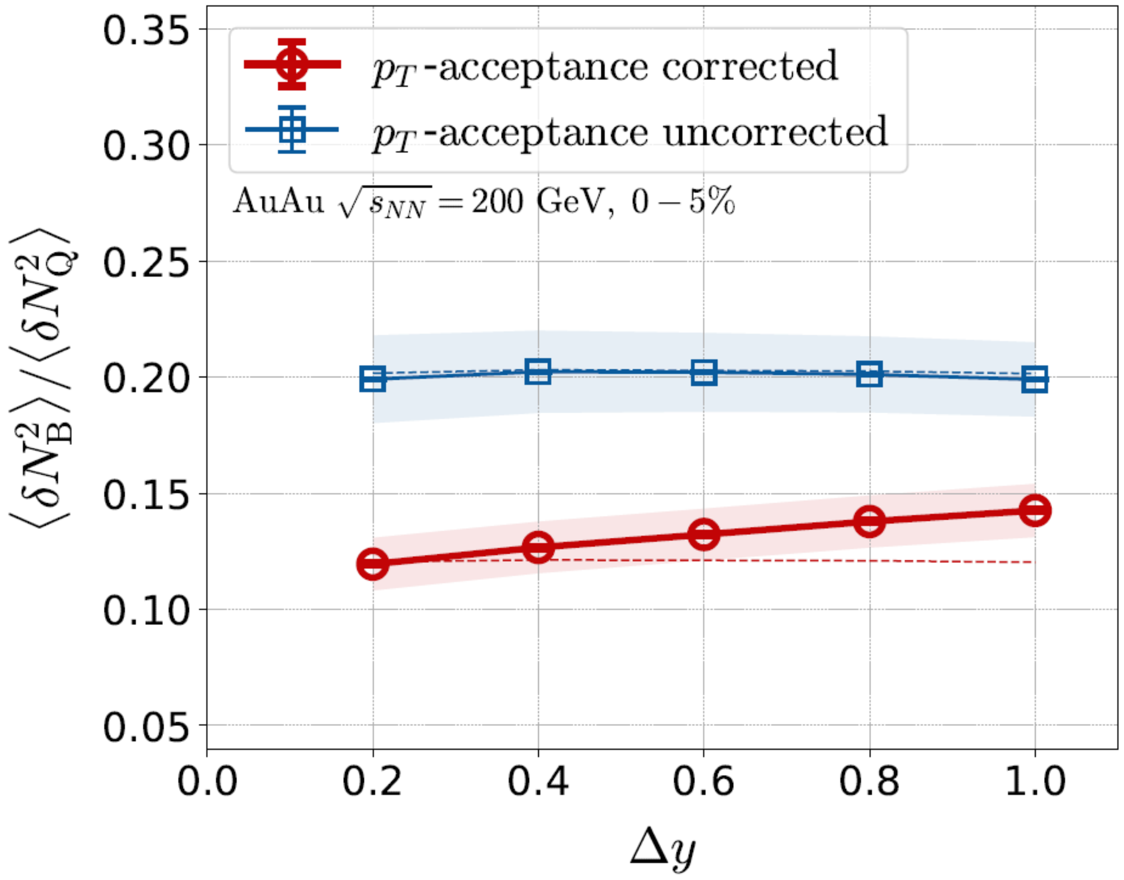
dashed: $\langle N^{\mathrm{tot}} \rangle$ Poisson

- ☐ Deviation from Poissonian is clarified by the acceptance correction.

$$\langle N_{\mathrm{net}}^2 \rangle_c^{\mathrm{corrected}} = \frac{1}{p^2} \Big(\langle n_{\mathrm{net}}^2 \rangle_c - (1-p) \langle n_{\mathrm{tot}} \rangle_c \Big)$$

MK, Asakawa, '12, '12

$\langle N_B^2 \rangle_c / \langle N_Q^2 \rangle_c$



p_T-acceptance **un**corrected

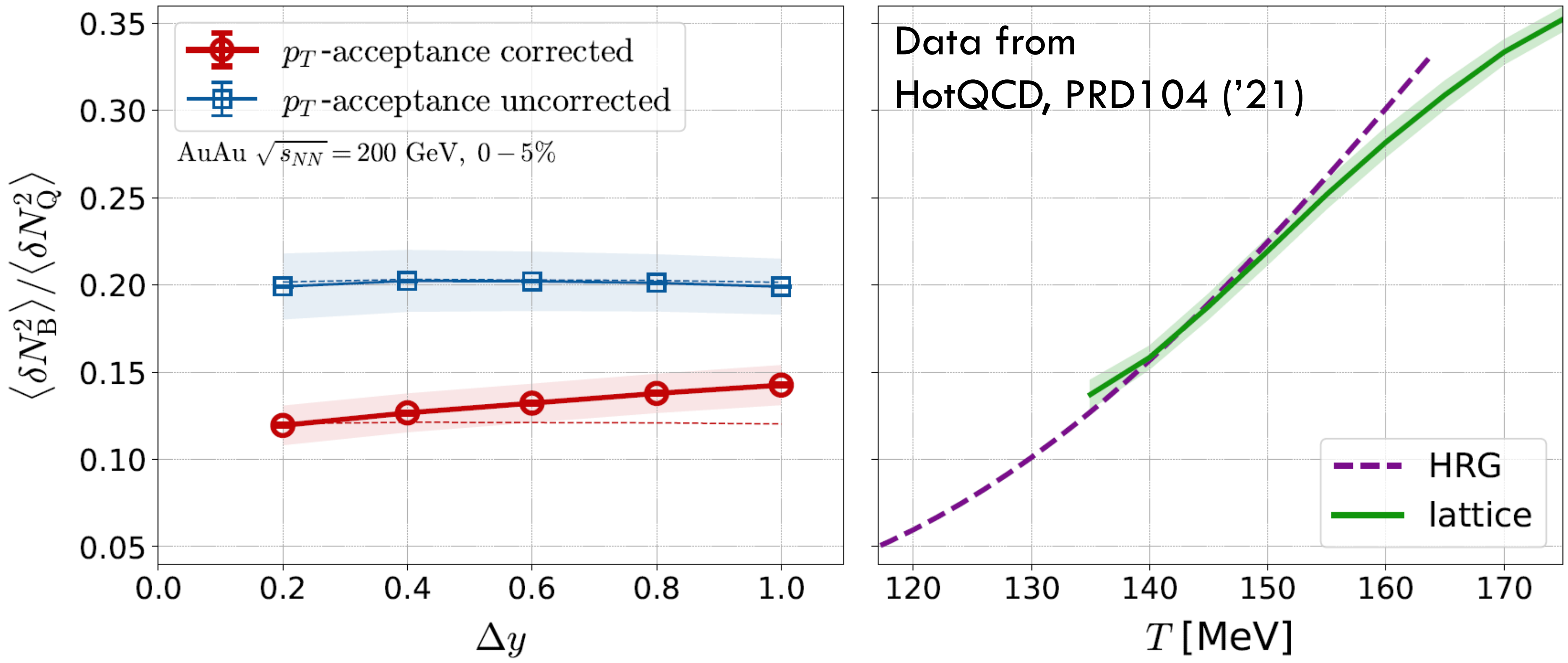
p_T-acceptance corrected

dashed: Poisson

- $\langle N_B^2 \rangle_c / \langle N_Q^2 \rangle_c$ becomes smaller due to the p_T-acceptance correction.
- Clear Δy dependence ➡ non-thermal effects behind fluctuations

HIC vs HRG&LAT

From data @ STAR | **HRG+Lattice**

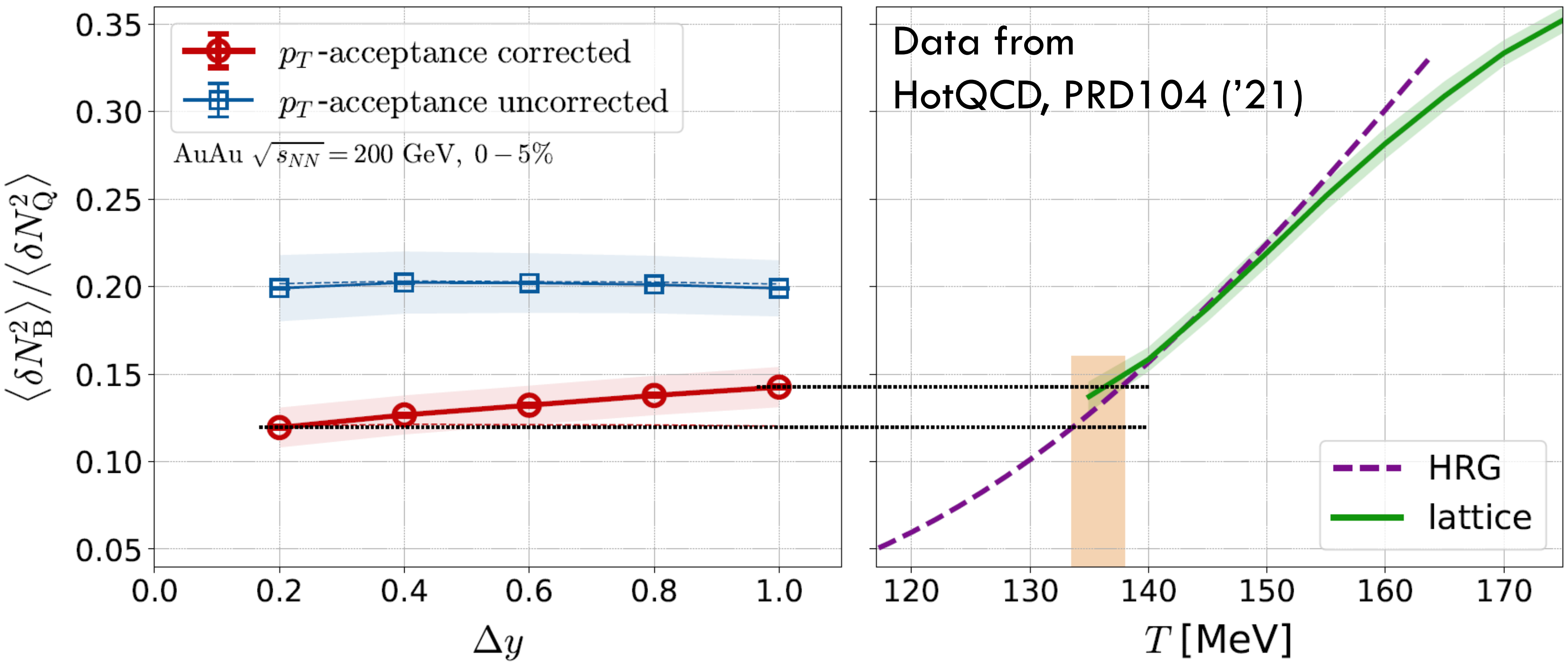


- $T = 134 \sim 138$ **MeV**
- Significantly lower than $T_{\rm chem}$

HRG: QMHRG2020
Bollweg+, PRD104, 7 ('21)
Volume dep. corrected
plot by MK

HIC vs HRG&LAT

From data @ STAR / HRG+Lattice



- $T = 134 \sim 138$ **MeV**
- Significantly lower than T_{chem}

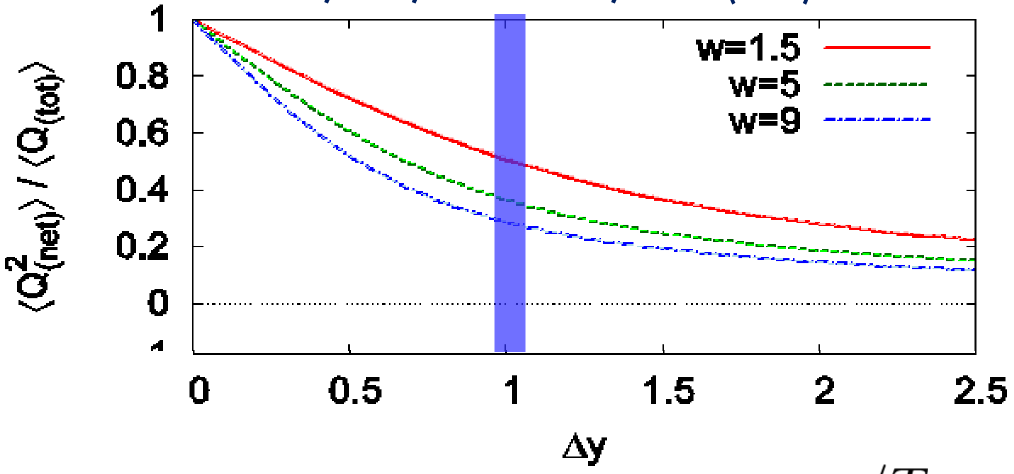
HRG: QMHRG2020
Bollweg+, PRD104, 7 ('21)
Volume dep. corrected
plot by MK

Effect of Diffusion and Rapidity Conversion

- Blurring due to diffusion & rapidity conversion ($Y \to y$)
  - Stronger modification in Q than B
- Resonance Decays
  - About 30% charged particles come from RD
  - Enhancement of charged particles

⇒
- Increase $\langle N_Q^2 \rangle$
- Reduce $\langle N_B^2 \rangle_c / \langle N_Q^2 \rangle_c$

Ohnishi, MK, Asakawa, PRC ('16)

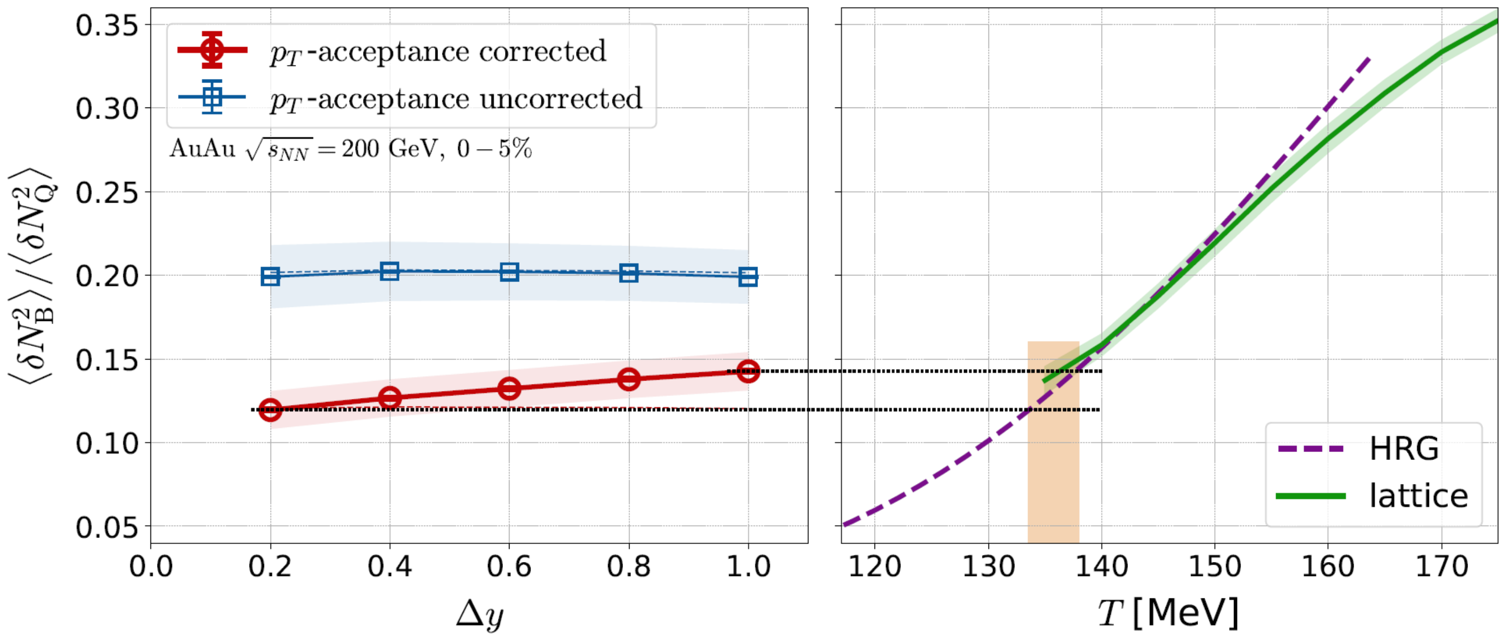


$w = m/T$

These effects will be more important for higher order cumulants!

Summary

- We estimated the cumulant ratio $\langle N_B^2\rangle_c/\langle N_Q^2\rangle_c$ at $\sqrt{s_{NN}} = 200$ GeV from STAR data.
- Acceptance correction for p_T cut has been adopted.
- Temperature estimated from the comparison with the HRG model is $T \simeq 134-138$ MeV, which is significantly lower than $T_{\rm chem}$.
- Existence of Δy dependence → Dynamical effects



Future Work

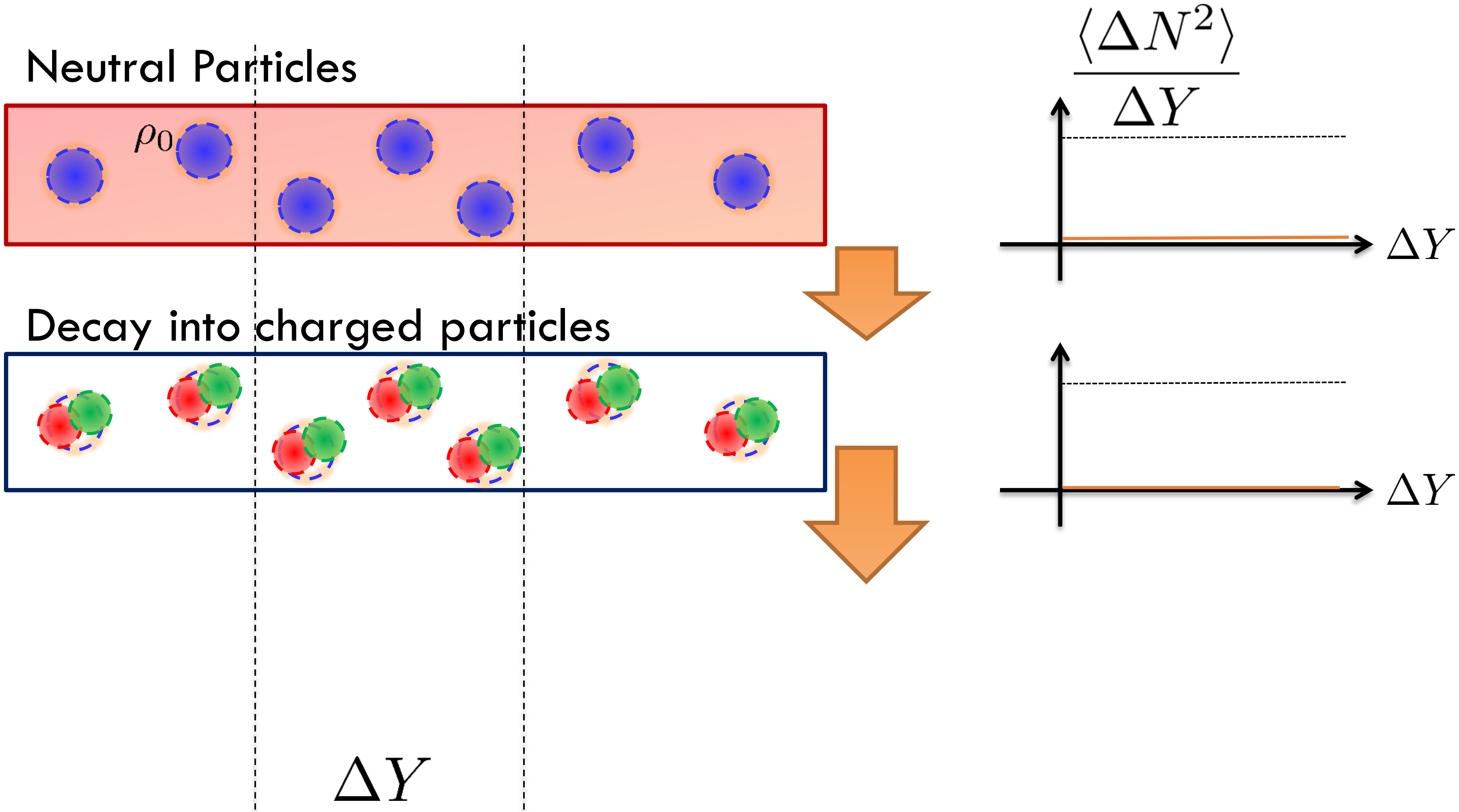
Theory

- Quantitative estimate on the diffusion, resonance decays
- Better treatment on the p_T-acceptance correction
- **Better understanding on lower order cumulants**

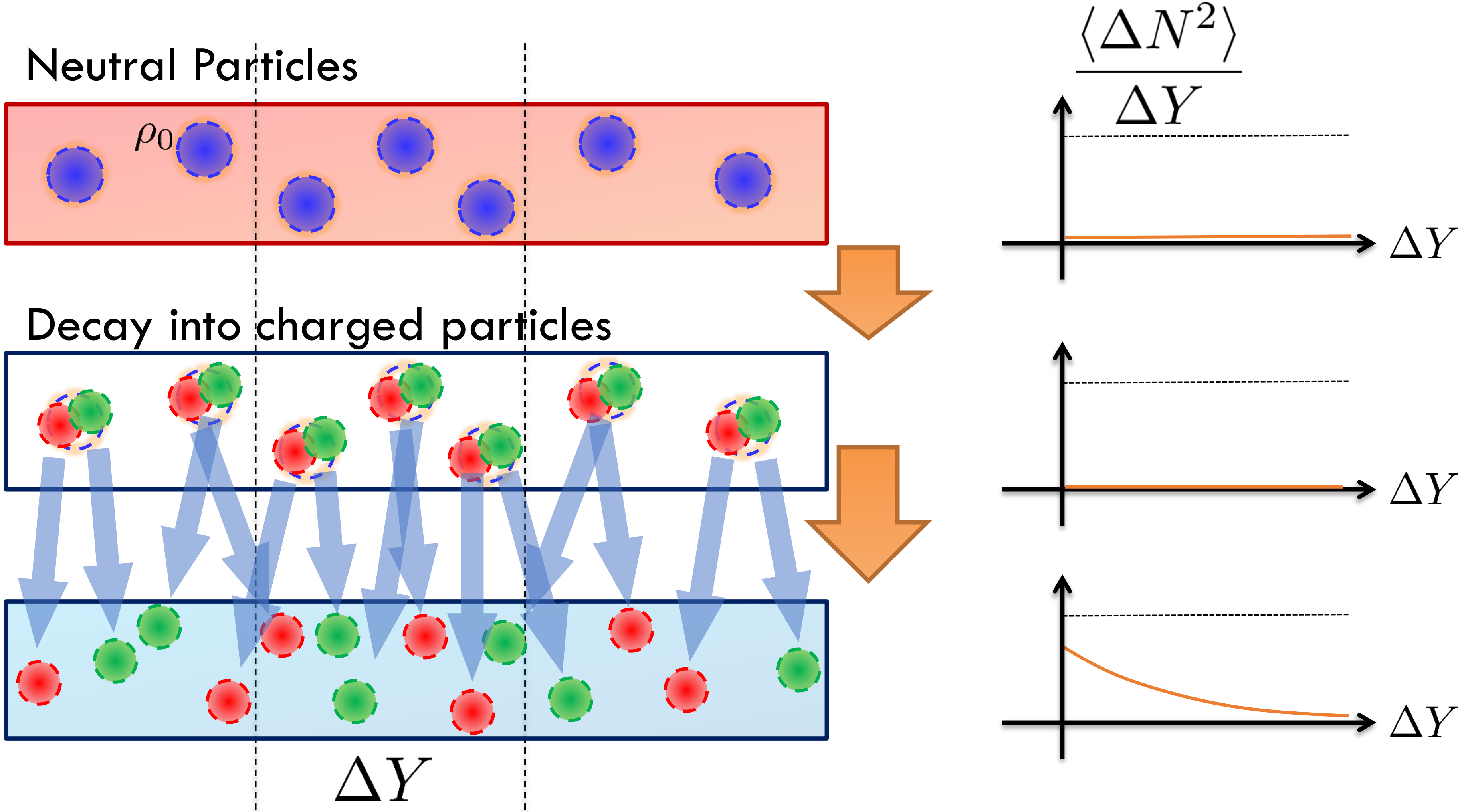
Experiment

- Measurement of $\langle N_Q^2 \rangle_c$ in rapidity space
- Wider acceptance for $\Delta y, p_T$
- BQ ratio at LHC
- Acceptance correction for higher order cumulants
- **Analysis of $\langle N_B^2 \rangle_c / \langle N_Q^2 \rangle_c$ and other ratios by experimental groups**
    - largest acceptance / same rapidity space / systematic errors

Resonance Decays

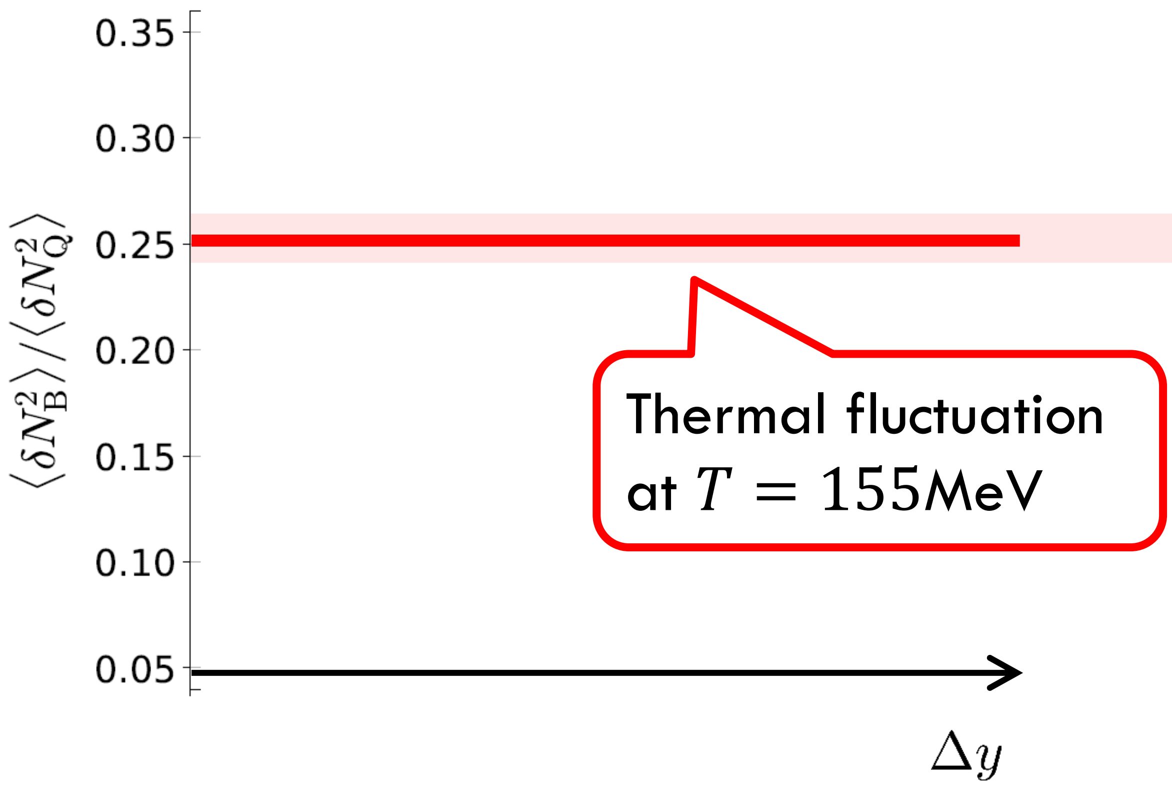


Resonance Decays

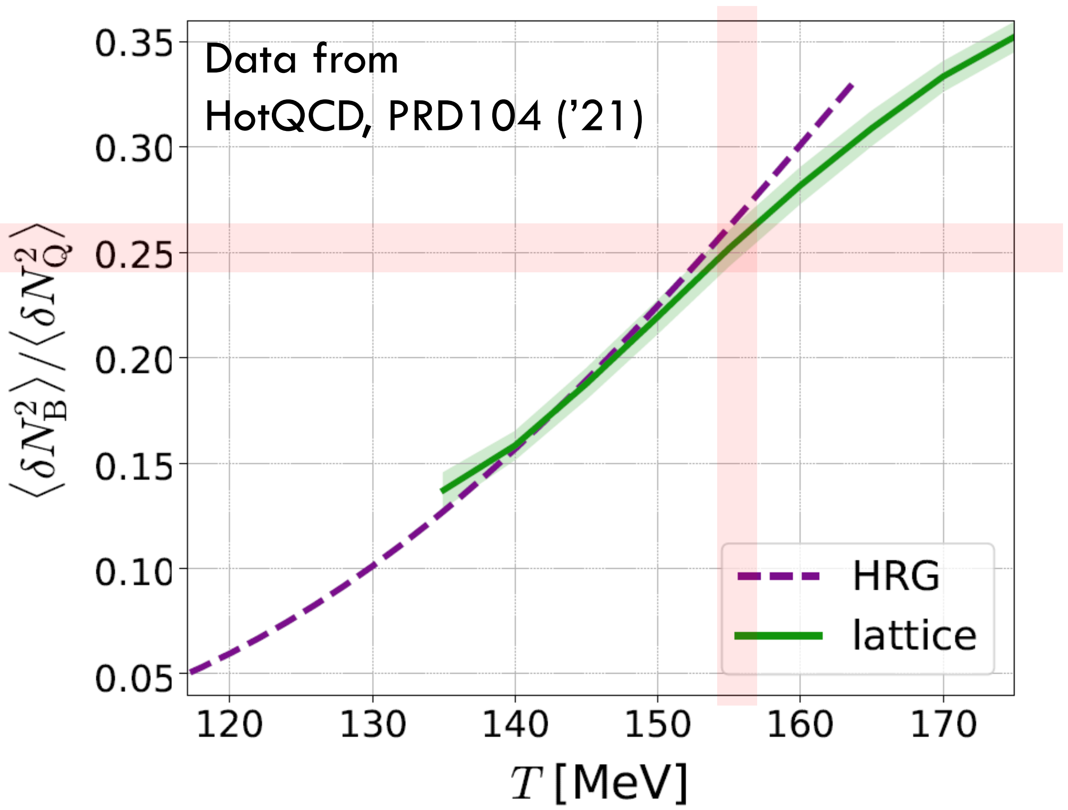


Expectations

Experimental data



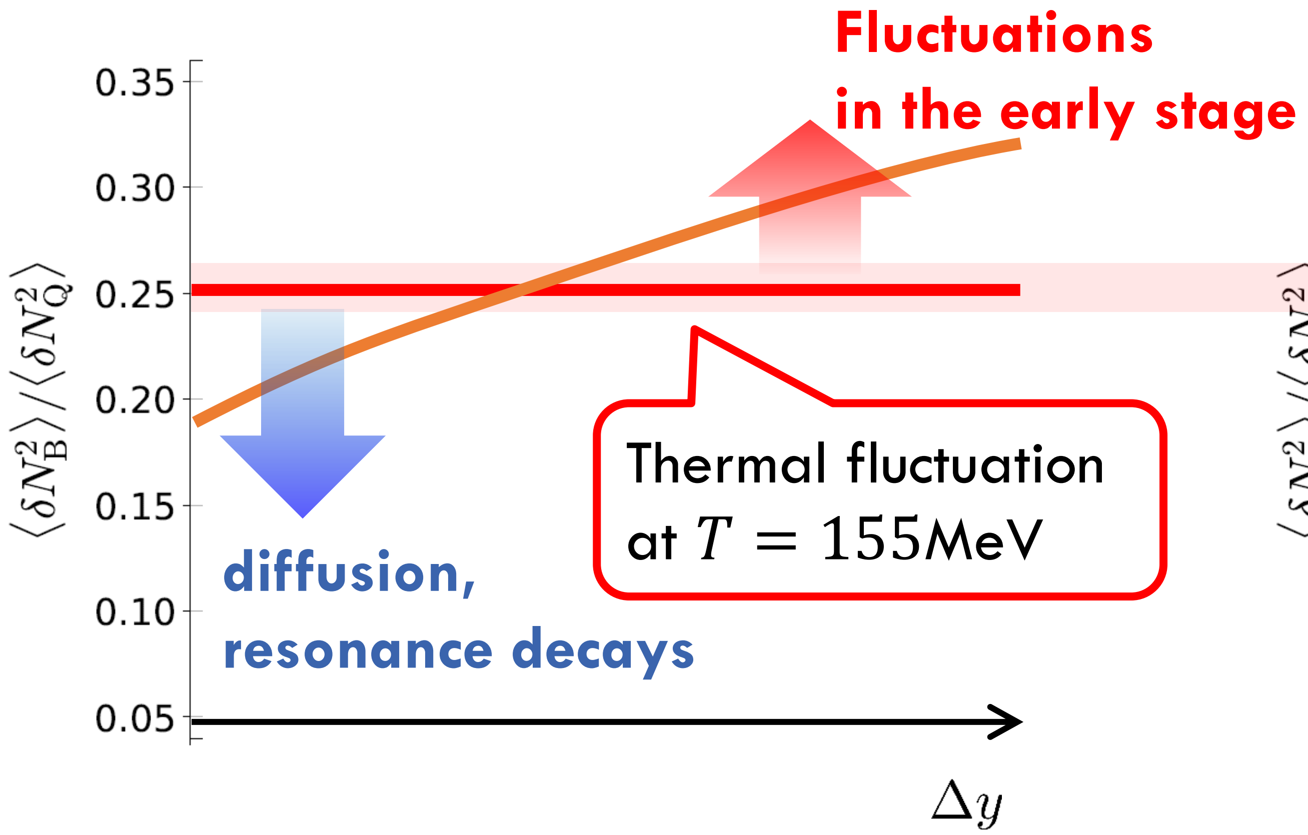
Lattice QCD + HRG



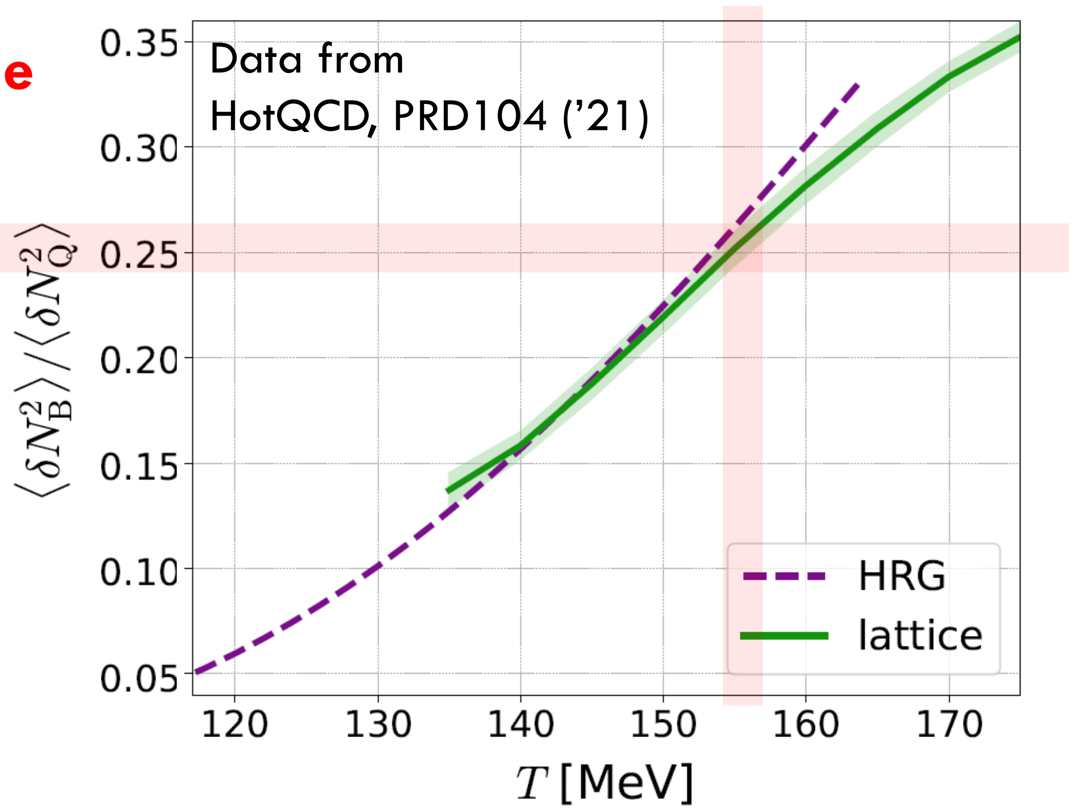
HRG: QMHG2020
Bollweg+, PRD104, 7 ('21)
plot by MK

Expectations

Experimental data



Lattice QCD + HRG



HRG: QMHG2020
Bollweg+, PRD104, 7 ('21)
plot by MK

Cumulants

Cumulants

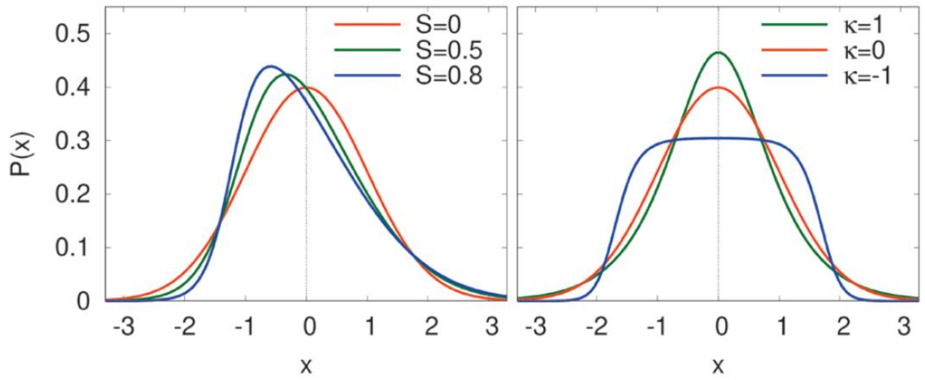
$$\begin{cases} \langle N \rangle_c = \langle N \rangle & \text{mean} \\ \langle N^2 \rangle_c = \langle \delta N^2 \rangle & \text{variance} \\ \langle N^3 \rangle_c = \langle \delta N^3 \rangle \\ \langle N^4 \rangle_c = \langle \delta N^4 \rangle - 3\langle \delta N^2 \rangle^2 \end{cases}$$

■ **Skewness**

$$S = \frac{\langle N^3 \rangle_c}{\langle N^2 \rangle_c^{3/2}}$$

■ **Kurtosis**

$$\kappa = \frac{\langle N^4 \rangle_c}{\langle N^2 \rangle_c^2}$$



■ Important Properties

- Extensive variables: $\langle N^m \rangle_c = \chi_m V$
- For Gauss distribution, $\langle N^3 \rangle_c = \langle N^4 \rangle_c = \cdots = 0$
- For Poisson distribution, $\langle N^2 \rangle_c = \langle N^3 \rangle_c = \langle N^4 \rangle_c = \cdots = \langle N \rangle$

Review: Asakawa, MK, PPNP **90** (2016)