現象論と観測量 ー QM2012から

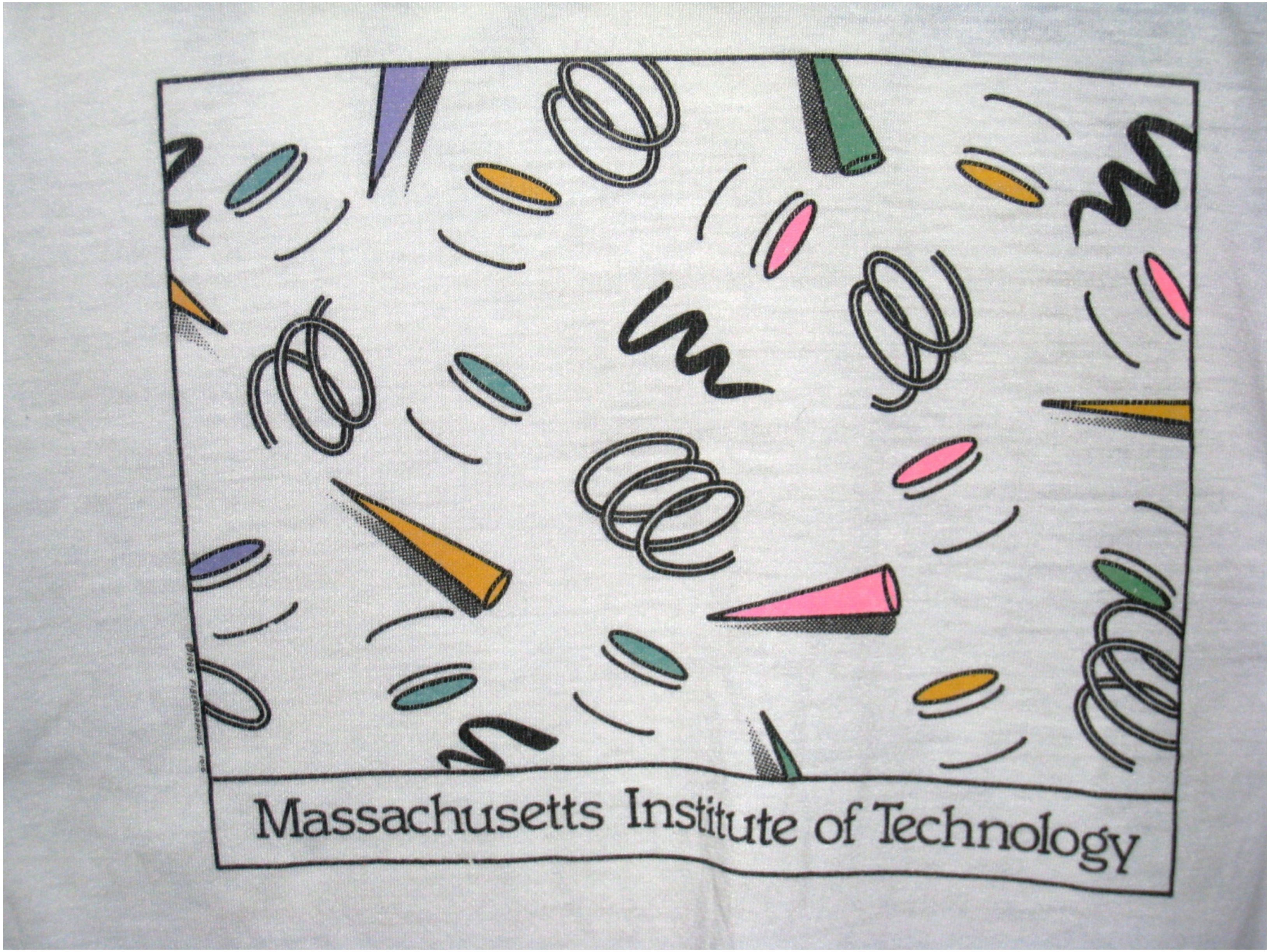
大阪大学大学院理学研究科物理学専攻

浅川　正之

September 6, 2012

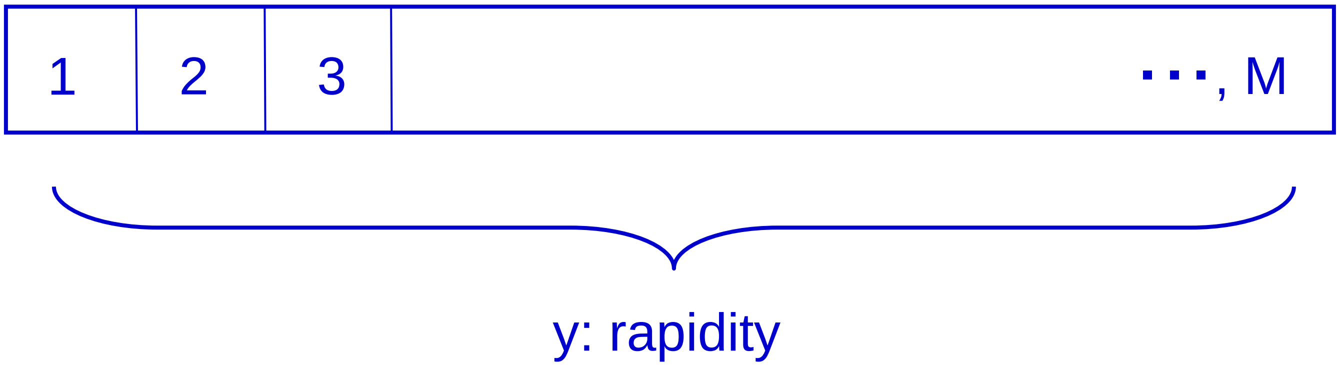
@ 名古屋大学 Heavy Ion Cafe/Pub

MIT で着ていたTシャツ



Intermittency

Białas & Peschanski (1986)



$$\langle F_i \rangle = M^{i-1} \left\langle \sum_{m=1}^{M} \frac{k_m (k_m - 1) \cdots (k_m - i + 1)}{N (N-1) \cdots (N - i + 1)} \right\rangle$$

Scaled factorial moment

NA49(poster@QM, and submitted to arXiv later)

Critical fluctuations of the proton density in A+A collisions at 158A GeV

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(NA49 Collaboration)

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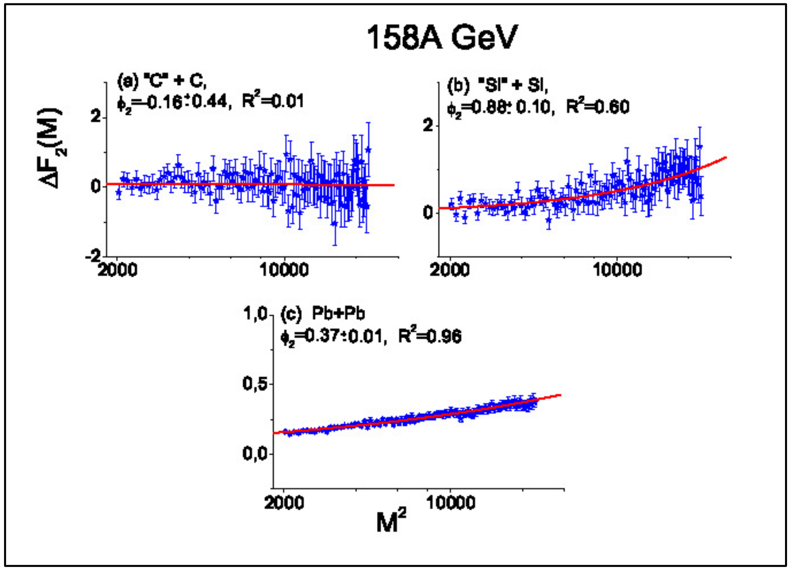
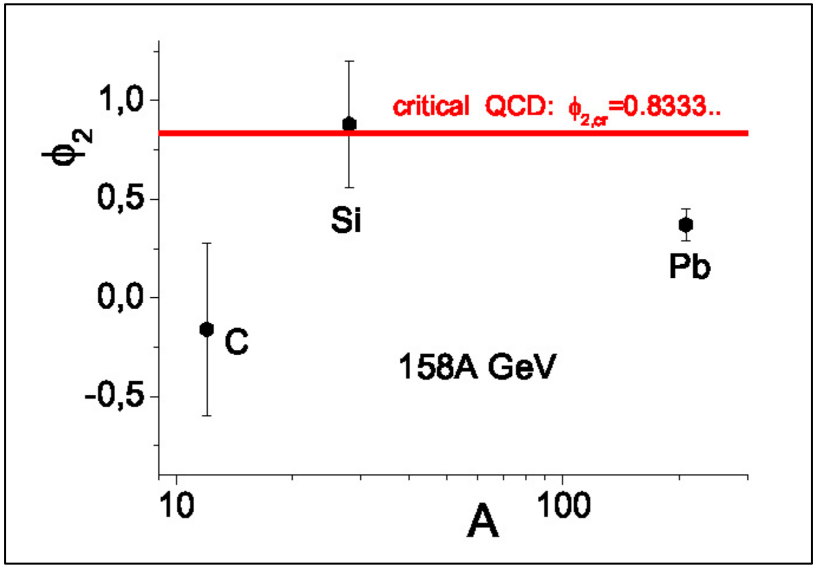
(Dated: August 28, 2012)

Studies of QCD suggest the existence of a critical point in the phase diagram of strongly interacting matter. Close to this point, according to recent theoretical investigations, the net-proton density carries the critical fluctuations of the chiral order parameter. Using intermittency analysis in the transverse momentum phase space of protons produced around midrapidity in the 12.5% most central C+C, Si+Si and Pb+Pb collisions at the maximum SPS energy of 158A GeV we find evidence of power-law fluctuations for the Si+Si and Pb+Pb data. The fitted power-law exponent approaches the value expected for critical fluctuations. This suggests that the freeze-out states of these two systems are located in the phase diagram in the neighbourhood of the chiral critical point.

PACS numbers: 25.75.-q

NA49(poster@QM, and submitted to arXiv later)



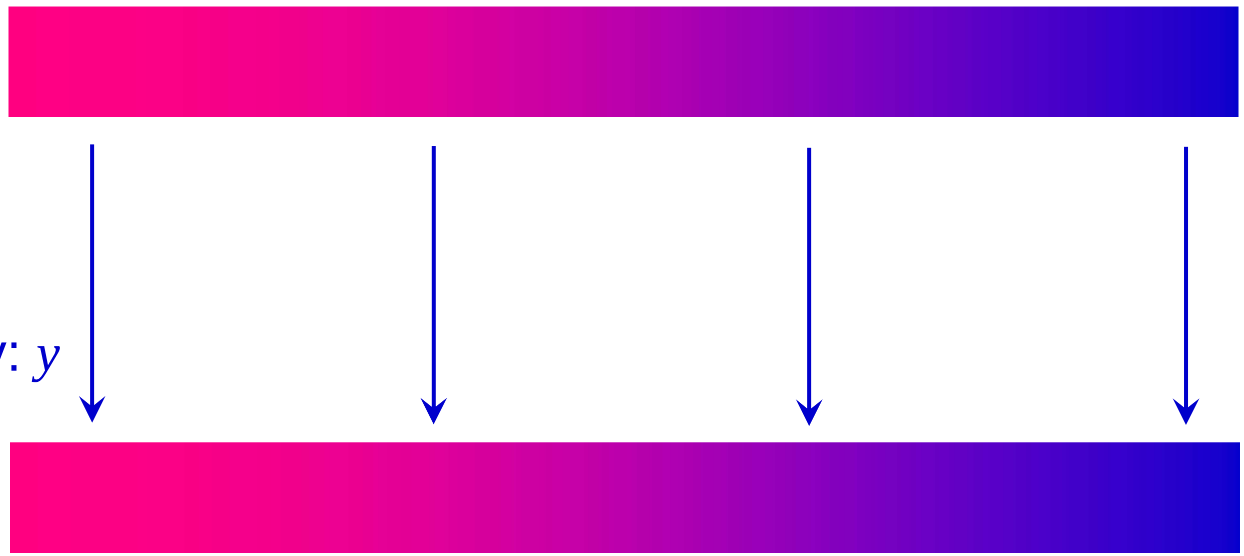


$$\Delta F_2(M) \propto (M^2)^{\phi_2}$$

ということで
Si+Si衝突におけるフリーズアウトはCPのそばにあるらしいと言っているが

Coordinate space & Momentum space

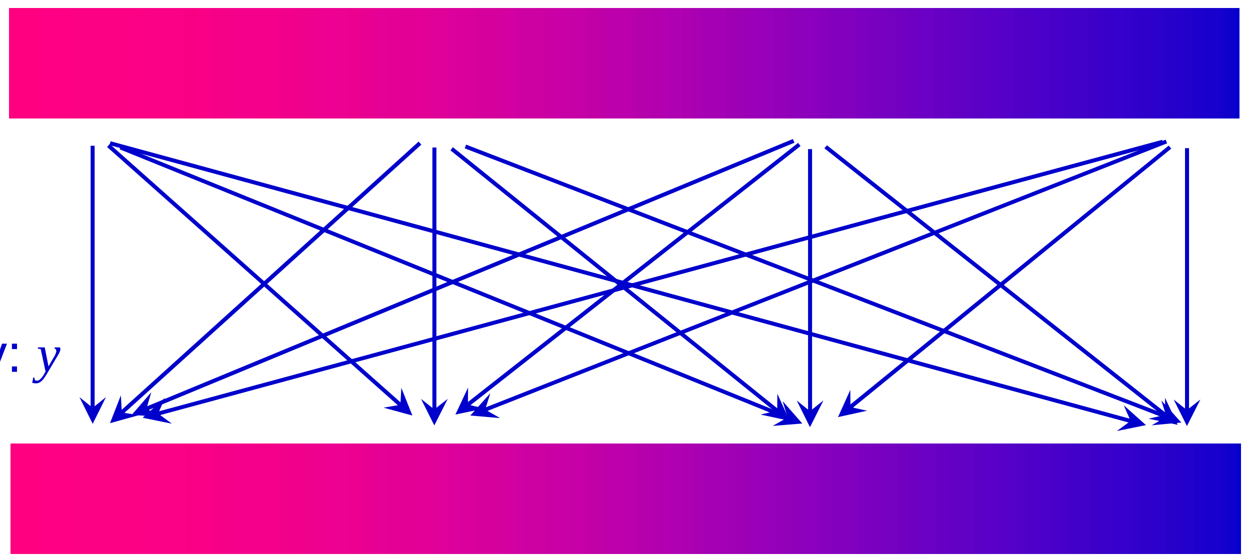
- coordinate space rapidity: η



- rapidity: y

Coordinate space & Momentum space

◆ coordinate space rapidity: η

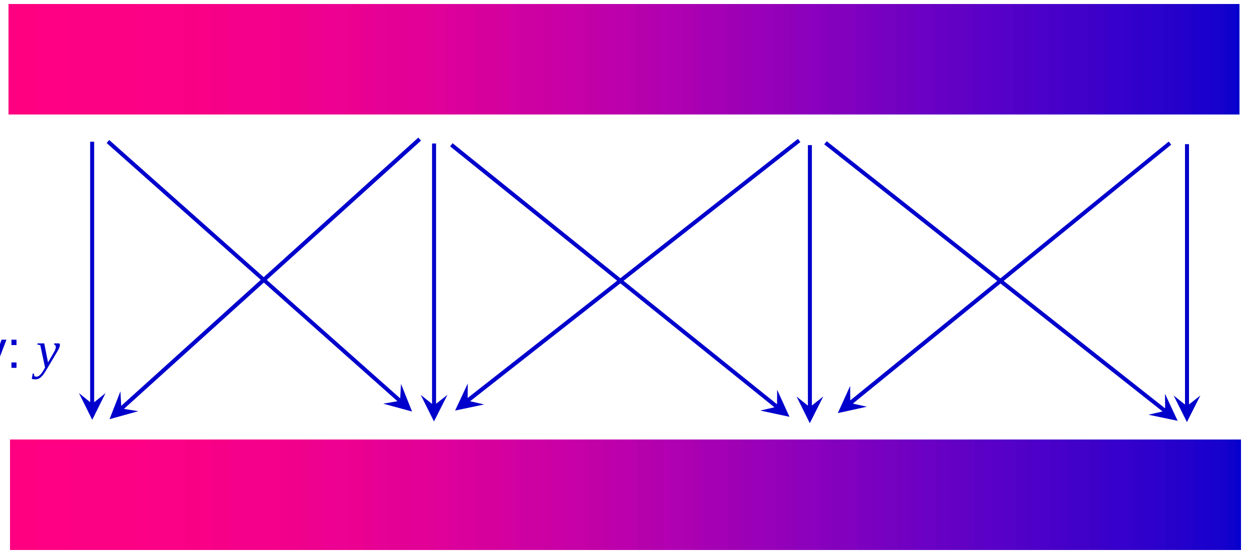


◆ rapidity: y

✓ Białas & Peschanski の頃はFlowという概念はあまりなかった（Standing Fireball）
cf. long emission time as a signature of 1st order phase transition

Coordinate space & Momentum space

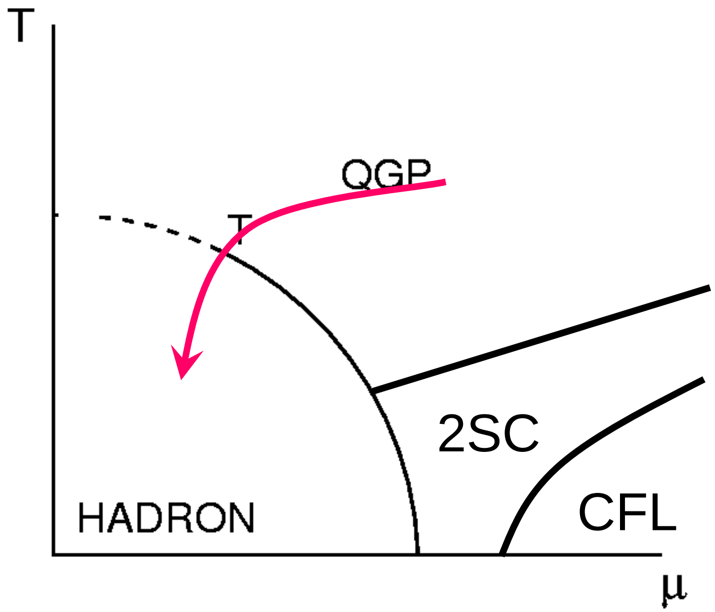
- coordinate space rapidity: η

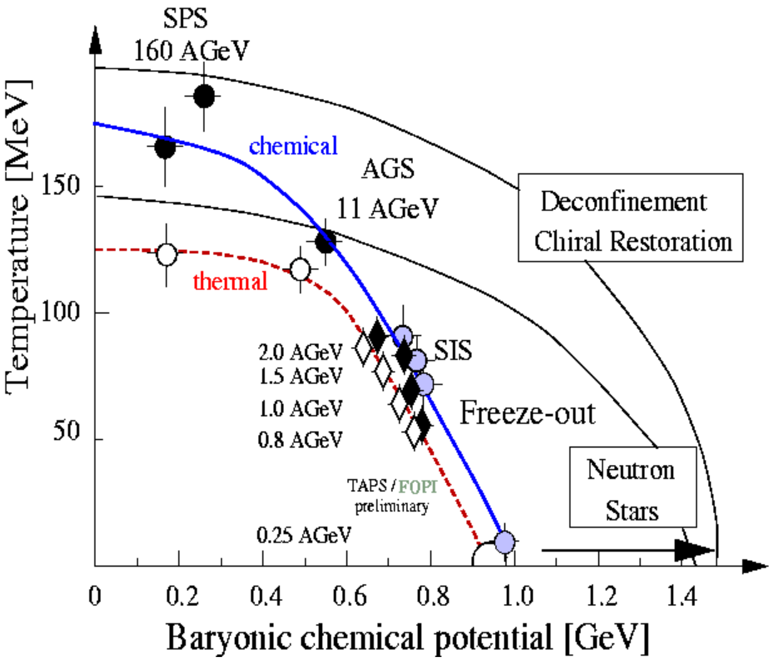


- rapidity: y

✓ ηとyはlooseに対応している(特にSPS）

Importance (Inevitability) of FSI

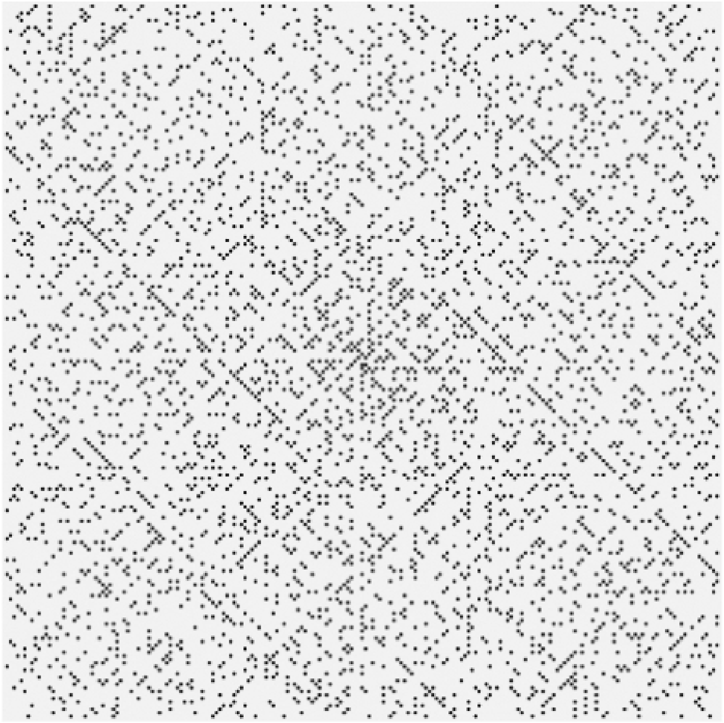




M. Asakawa (Osaka University)

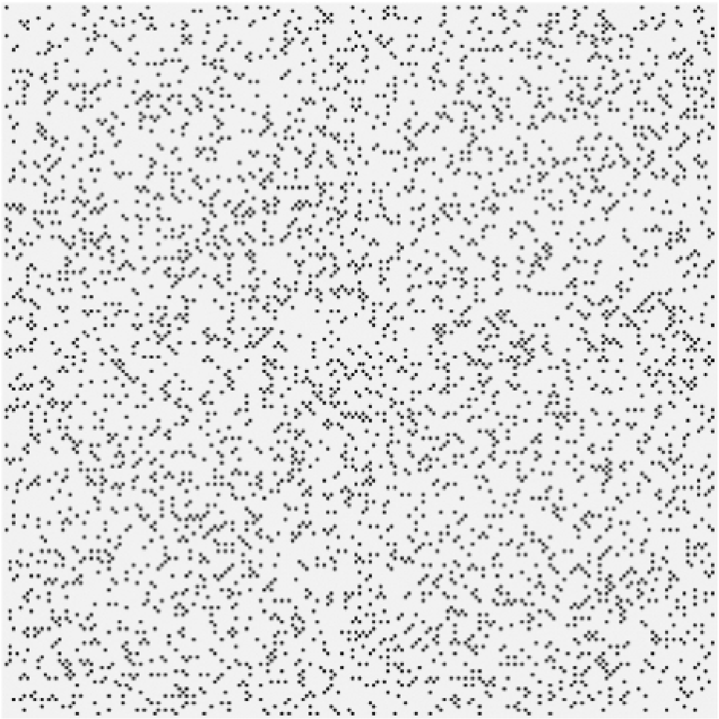
ウラムの螺旋

201×201個の自然数を螺旋に並べた
この範囲には4236個の素数がある



数論的意味は未解決

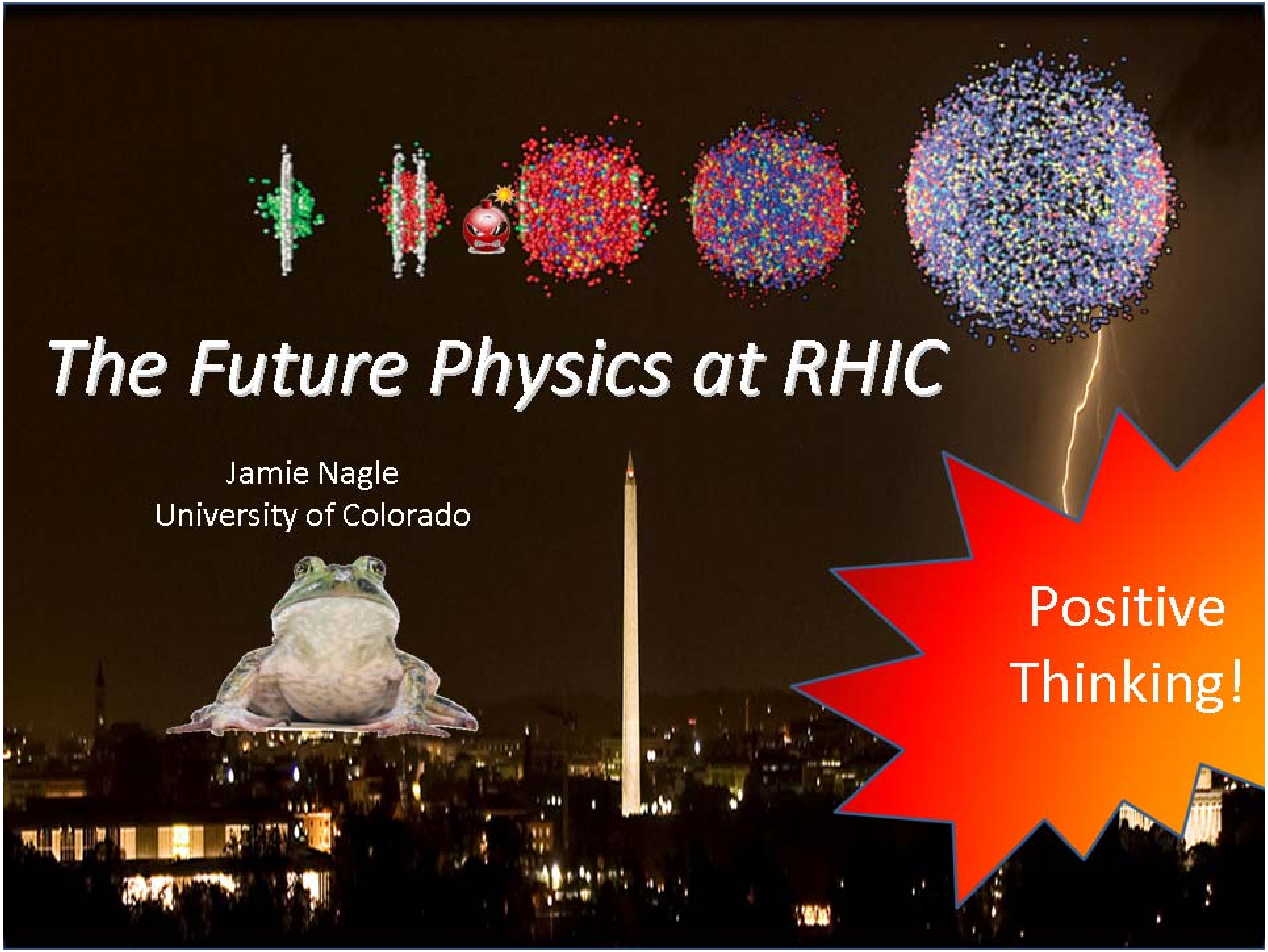
201×201個の自然数から4236個の
奇数をランダムに選んだ



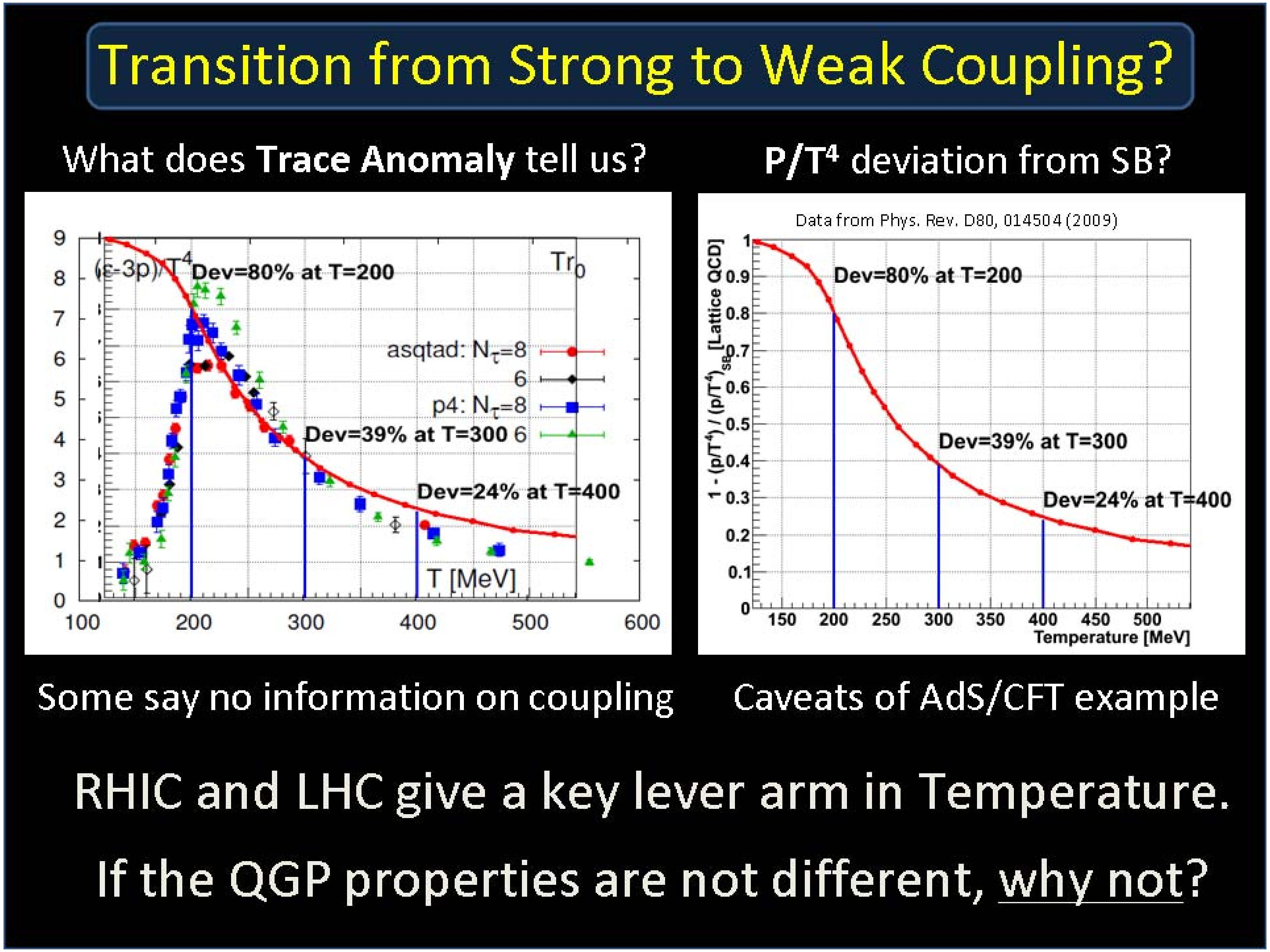
ノイズを加えても多分同じ

朋優学院サイエンスサークルホームページより転載

Trace Anomaly?



Trace Anomaly?



このような考察にならないように、
昨年弘前で使ったスライドを用いて説明します

Interaction Measure

この量 $\dfrac{e-3p}{T^4}$ は interaction measure と呼ばれている

超相対論的自由ガスでは $e=3p$ が成り立つ(と思われている)ため

$$e-3p = T^{\mu}_{\mu} = \frac{\beta(g)}{g} F^{\mu\nu} F_{\mu\nu}$$

なので、trace anomaly とも呼ばれている

素朴な疑問

✓ グルーオン凝縮の絶対値は真空中の方が大きかったのでは?

✓ 本当に、超相対論的自由ガスでは $e=3p$ が成り立つのでしょうか?

Interaction measure does not measure interaction

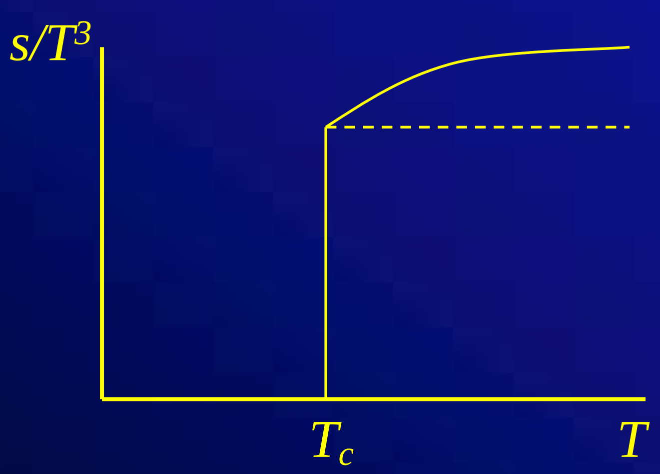
At $\mu = 0$

$$P(T) = \int_0^T s(t)dt$$

$$e(T) = Ts(T) - P(T)$$

格子上では T=0 で e=p=0 に規格化されているので

相転移を単純化



$\dfrac{e-3p}{T^4}$ はいずれの場合でも、T_c までは0

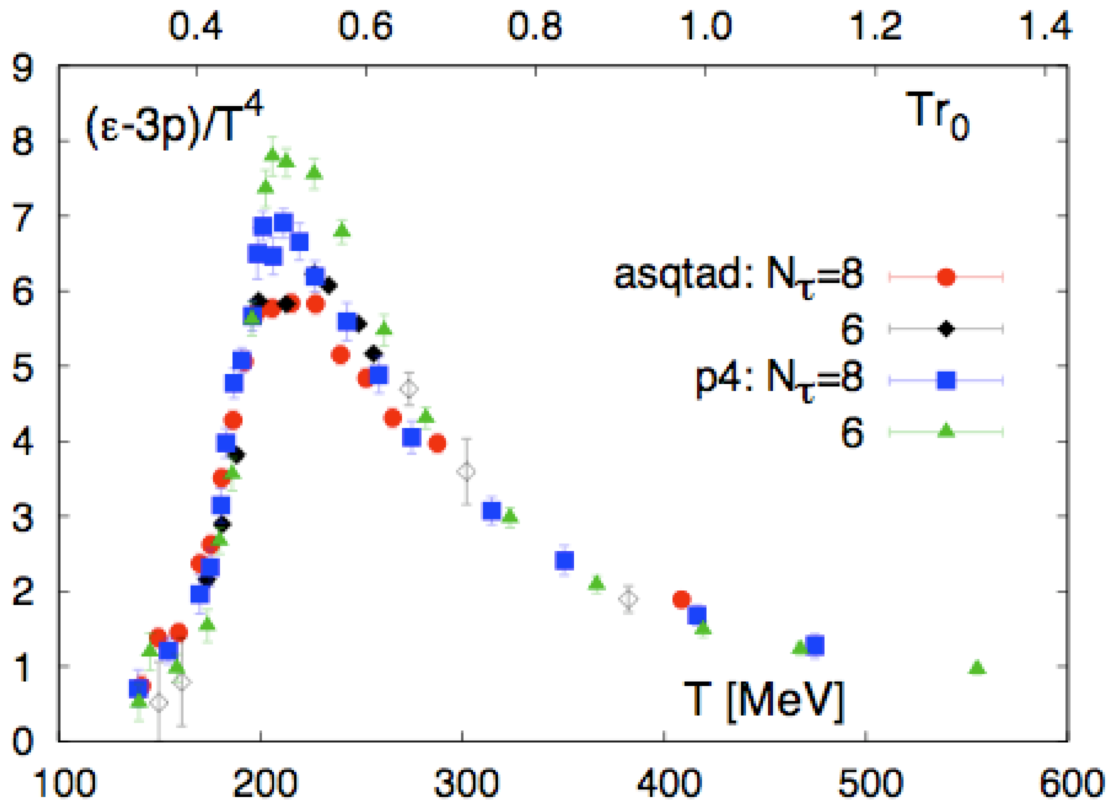
熱力学は $s(T)$ が増加関数としか言わないが、、、

有効自由度 $n(T)=s/T^3$ を考えて、$n(T)$ が
増加関数とすると（格子の結果もそうなっている）

e-$3p$ は増加関数になる ⇒ e=$3p$ とは絶対ならない

M. Asakawa (Osaka University)

QCD thermodynamics is qualitatively different above 2-3 T_c



- Beware: - Lattice shows $\varepsilon - 3p \propto \Lambda_{QCD}^2 T^2$

  - naïve quasi-particle models $\varepsilon - 3p \propto T^4$

  - LHC reaches well beyond T=400 MeV, where QCD thermodynamics is different

Wiedemann QM2009

さて本題

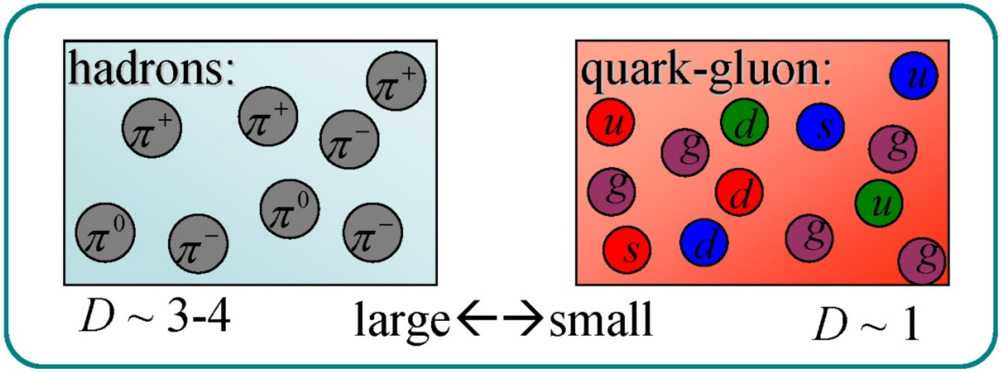
(Net-)Charge Fluctuations

Asakawa, Heinz, Muller, '00
Jeon, Koch, '00

- D-measure: $D = 4\dfrac{\langle (\delta N_Q)^2 \rangle}{N_{ch}}$

N_Q: net charge #
N_{ch}: total #

- values of D:



- When is experimentally measured D formed?
  - **Conserved charges** can **remember** fluctuations at early stage, if diffusions are sufficiently slow.

北沢さんの前回のHIC/HIPでのスライド

Charge Fluctuation

(Net-)Charge Fluctuations

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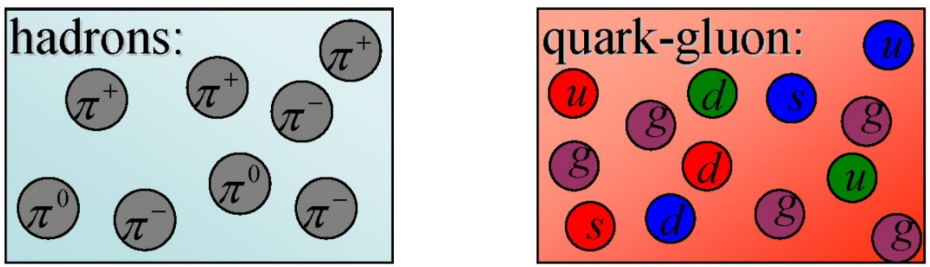


$D \sim 3\text{-}4$ large←→small $D \sim 1$

リコンビネーションによる説明

quark matter

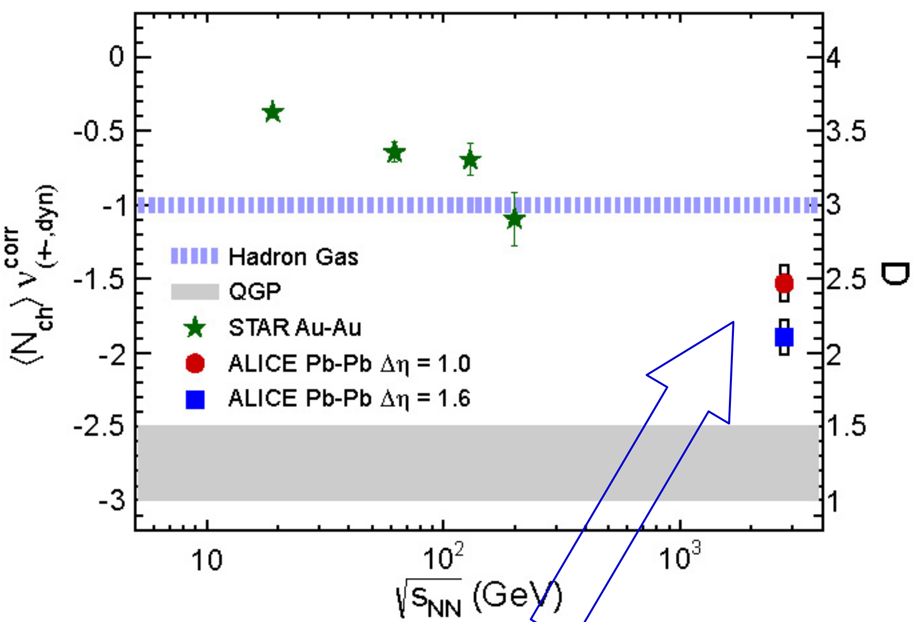
実験結果： D~3

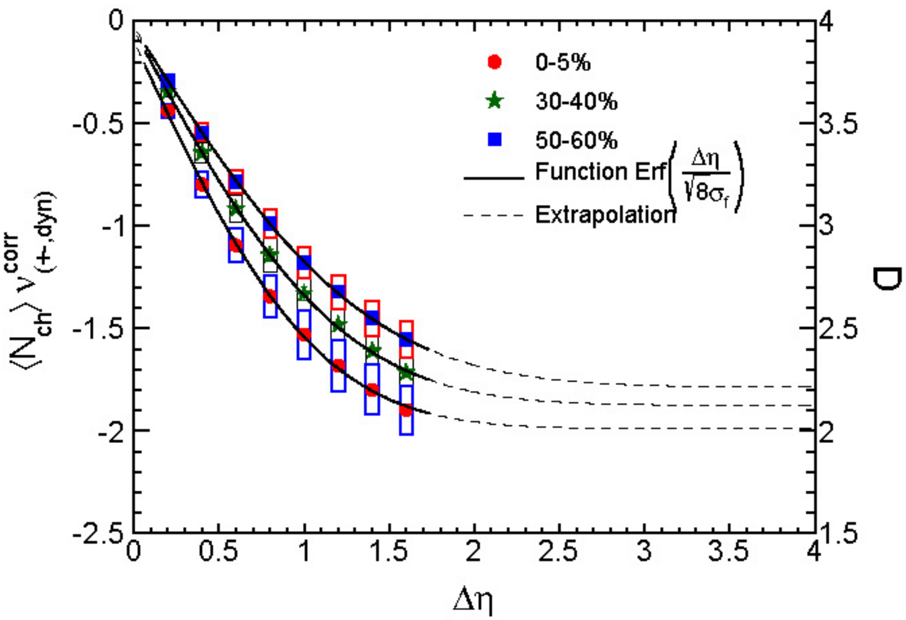
PHENIX ’02, STAR ’03

Counterarguments in

Bialas(’02), Nonaka, *et al.*(’05)

ALICE Paper(arXiv:1207:6068) & QM parallel talk

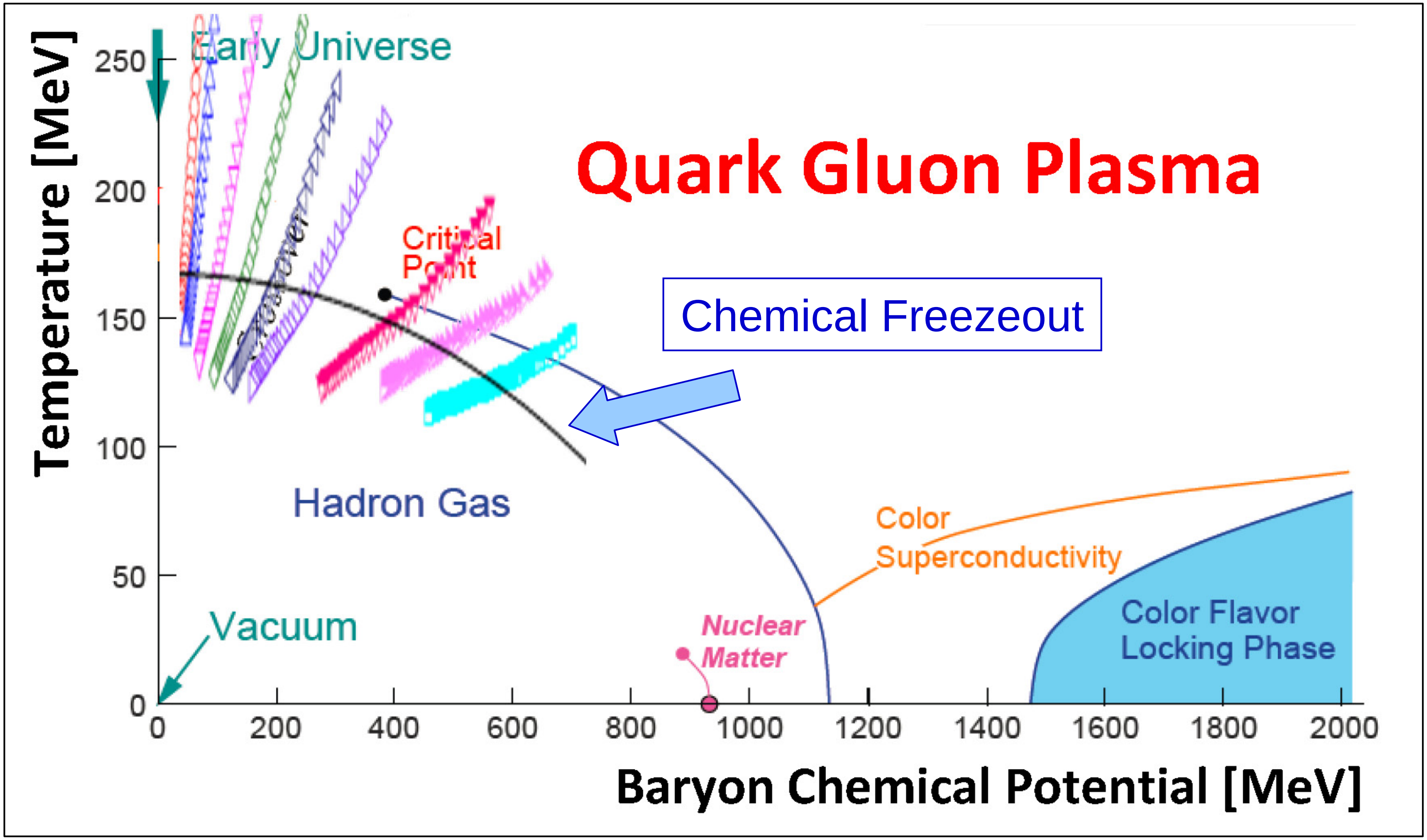




LHCはRHICとは違うという数少ない定量的結果の一つ

Gluonic degrees of freedom?

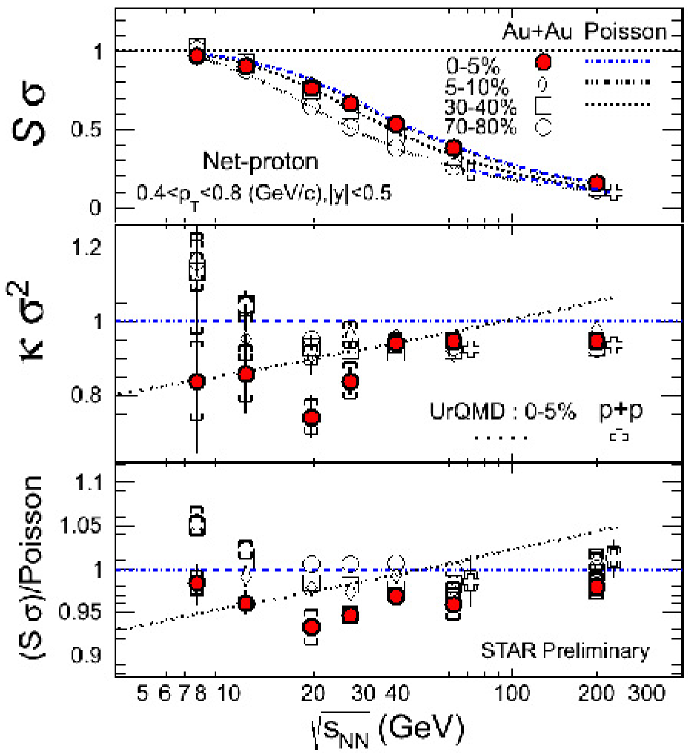
RHIC Energy Scan



Proton Number Cumulants and Their Ratios

Higher Moments of Net-protons

$$\sigma^2 = \langle (N - \langle N \rangle)^2 \rangle$$
$$S = \langle (N - \langle N \rangle)^3 \rangle / \sigma^3$$
$$\kappa = \langle (N - \langle N \rangle)^4 \rangle / \sigma^4 - 3$$



- Higher moments - more sensitive to Critical Point induced fluctuations.
- Deviation from Poisson baseline in 0-5% collisions at >7.7 GeV.
- Above Poisson baseline in peripheral collisions below 19.6 GeV.
- UrQMD shows monotonic behavior.
- Need precision measurements at low energies.

Net-proton/Net-charge/Net-kaon

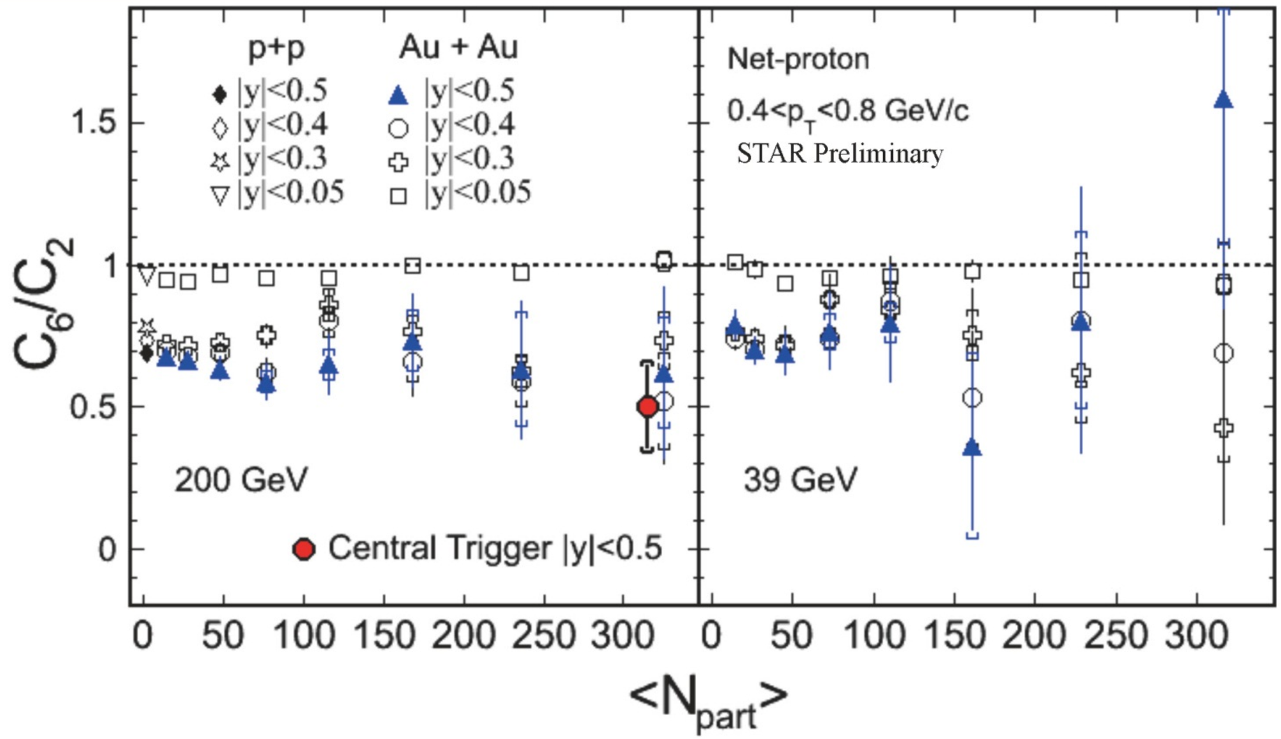
Luo, 7B, Fri.; McDonald, 7B, Fri.

Li/Sahoo/Sarkar, poster #215/557/394

STAR

Proton Number Cumulants and Their Ratios

Centrality and Rapidity Width Dependence



- Deviation from Poisson (unity) expectation observed
- Most of the results are below unity
- The smaller the rapidity bin, the closer are the values to unity

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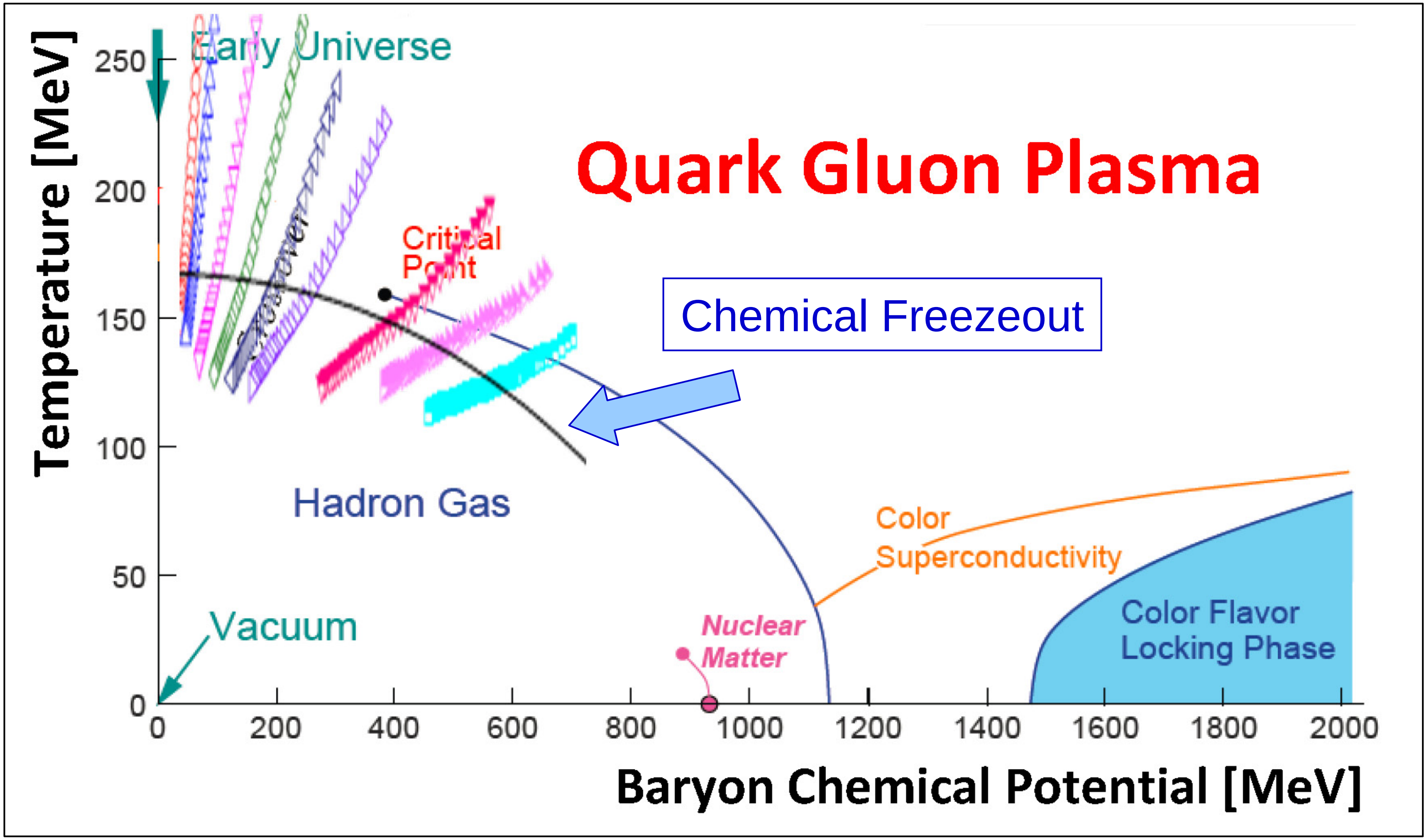
L. Chen (STAR Collaboration) @QM2012

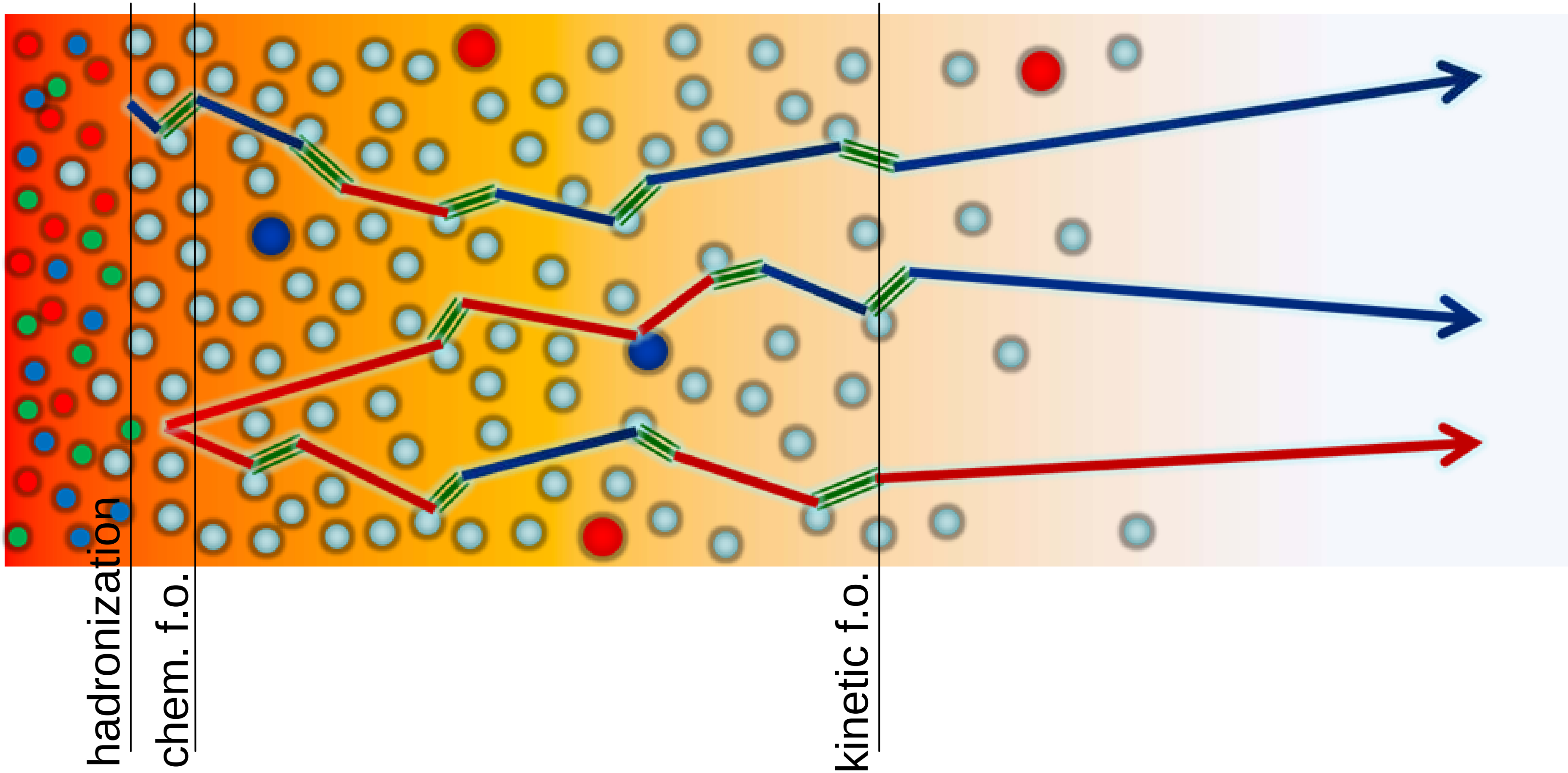
よくある誤解

Net Proton Number は保存量



"Proton Number is a proxy of Baryon Number" @ あるpresentation
(neutron number ≠観測可能量)

Thanks to last HIC/HIP meeting



$$P_i(N_p, N_n, N_{\bar{p}}, N_{\bar{n}}) \Rightarrow P_f(N_p, N_n, N_{\bar{p}}, N_{\bar{n}})$$

Chemical Freezeoutの後でも、resonanceは生成される！

Proton and Nucleon Moments

$N_{\mathrm{N}} \longrightarrow N_p$

$$\left\langle \left(\delta N_p^{(\mathrm{net})}\right)^3 \right\rangle = \frac{1}{8}\left\langle \left(\delta N_{\mathrm{N}}^{(\mathrm{net})}\right)^3 \right\rangle + \frac{3}{8}\left\langle \delta N_{\mathrm{N}}^{(\mathrm{net})} \delta N_{\mathrm{N}}^{(\mathrm{tot})} \right\rangle$$

$$\left\langle \left(\delta N_p^{(\mathrm{net})}\right)^4 \right\rangle_c = \frac{1}{16}\left\langle \left(\delta N_{\mathrm{N}}^{(\mathrm{net})}\right)^4 \right\rangle_c + \frac{3}{8}\left\langle \left(\delta N_{\mathrm{N}}^{(\mathrm{net})}\right)^2 \delta N_{\mathrm{N}}^{(\mathrm{tot})} \right\rangle + \frac{3}{16}\left\langle \left(\delta N_{\mathrm{N}}^{(\mathrm{net})}\right)^2 \right\rangle - \frac{1}{8}\left\langle N_{\mathrm{N}}^{(\mathrm{tot})} \right\rangle$$

$N_p \longrightarrow N_{\mathrm{N}}$

$$\left\langle \left(\delta N_{\mathrm{N}}^{(\mathrm{net})}\right)^3 \right\rangle = 8\left\langle \left(\delta N_p^{(\mathrm{net})}\right)^3 \right\rangle - 12\left\langle \delta N_p^{(\mathrm{net})} \delta N_p^{(\mathrm{tot})} \right\rangle + 6\left\langle N_p^{(\mathrm{net})} \right\rangle$$

$$\left\langle \left(\delta N_{\mathrm{N}}^{(\mathrm{net})}\right)^4 \right\rangle_c = 16\left\langle \left(\delta N_p^{(\mathrm{net})}\right)^4 \right\rangle_c - 48\left\langle \left(\delta N_p^{(\mathrm{net})}\right)^2 \delta N_p^{(\mathrm{tot})} \right\rangle + 48\left\langle \left(\delta N_p^{(\mathrm{net})}\right)^2 \right\rangle + 12\left\langle \left(\delta N_p^{(\mathrm{tot})}\right)^2 \right\rangle - 26\left\langle N_p^{(\mathrm{tot})} \right\rangle$$

$$\left\langle \delta N^4 \right\rangle_c = \left\langle (\delta N)^4 \right\rangle - 3\left\langle (\delta N)^2 \right\rangle^2$$

Kitazawa and M.A., 2011, 2012

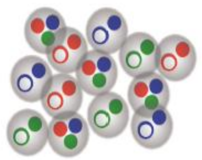
Balance Function

QGP properties

Relevant charge carriers:

Jeon, Koch, PRL 85, 2072 (2000).
Asakawa et al., *PRL 85, 2076 (2000).*

QGP: Charge unit = fractional



Hadron Gas: Charge unit = 1

- Identify relevant charge carriers
- Depends strongly on the originating phase
- Event-by-event net-charge fluctuations:

$$\nu_{(+-,dyn)} = \frac{\langle N_+(N_+-1)\rangle}{\langle N_+\rangle^2} + \frac{\langle N_-(N_--1)\rangle}{\langle N_-\rangle^2} - 2\frac{\langle N_+N_-\rangle}{\langle N_+\rangle\langle N_-\rangle}$$

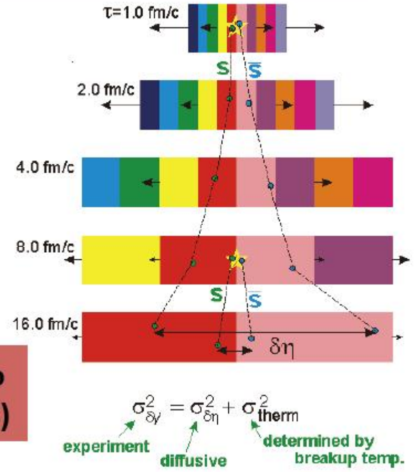
Poster: S. Jena (16 Aug - Nr. 421)

Balancing charge separation:

Bass, Danielewicz, Pratt, PRL 85, 2689 (2000).

- Correlation of balancing charges
  - Collective motion
  - Initial charge separation at freeze-out
  - Time of hadronization
- Balance function (e.g. for $\Delta\eta$):

$$B(\Delta\eta) = \frac{1}{2}\left\{\frac{N_{+-}(\Delta\eta) - N_{++}(\Delta\eta)}{N_+} + \frac{N_{-+}(\Delta\eta) - N_{--}(\Delta\eta)}{N_-}\right\}$$



Poster: A. Manso (16 Aug - Nr. 428)

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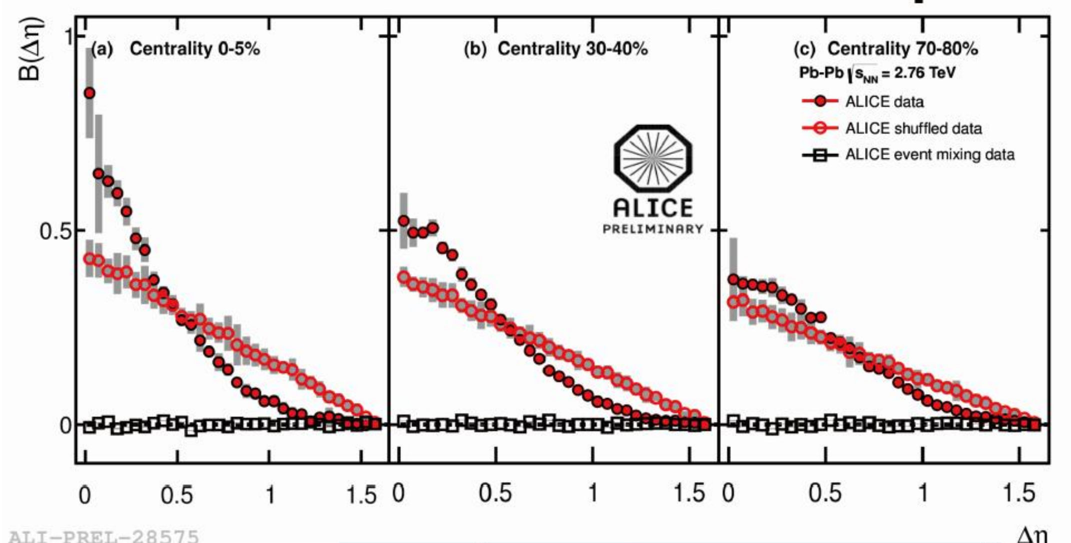
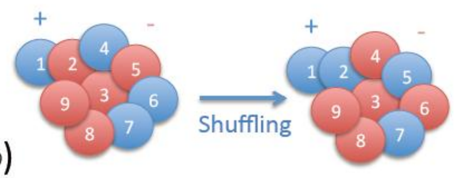
Weber, QM2012

Balance Function

Balance functions (Δη)



- Experimental definition: $B(\Delta\eta) = \frac{1}{2}\left\{\frac{N_{+-}(\Delta\eta) - N_{++}(\Delta\eta)}{N_{+}} + \frac{N_{-+}(\Delta\eta) - N_{--}(\Delta\eta)}{N_{-}}\right\}$
- Shuffled events: break charge-momentum correlation (acceptance effect)
- Mixed events: break momentum correlations (charge dependent effects on acceptance)
- Data: Mixed events subtracted (important for Δφ)



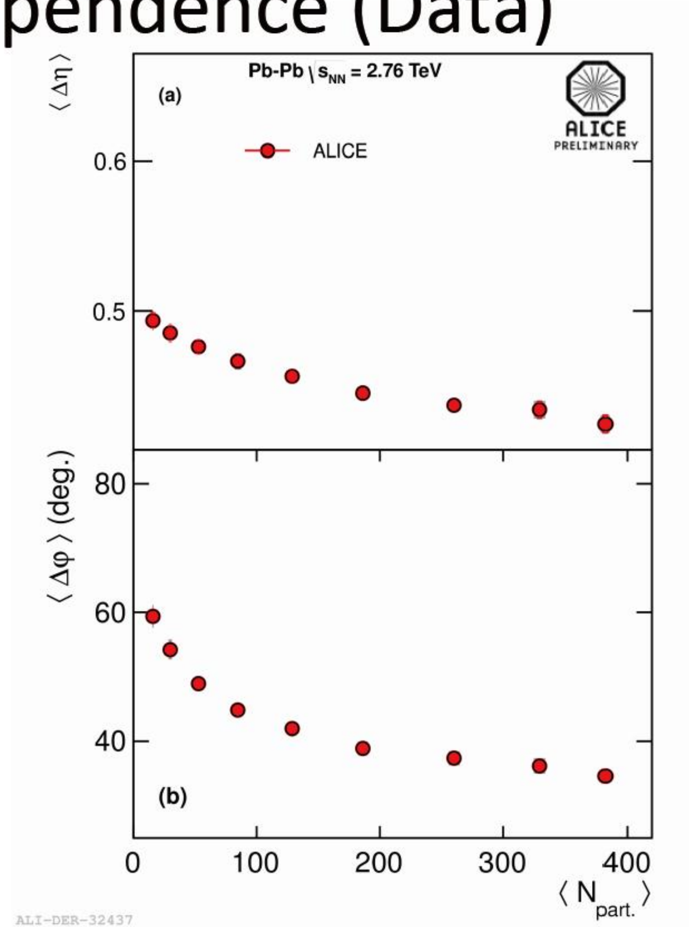
Weber, QM2012

Balance Function

Centrality dependence (Data)

Data:

- Strong centrality dependence



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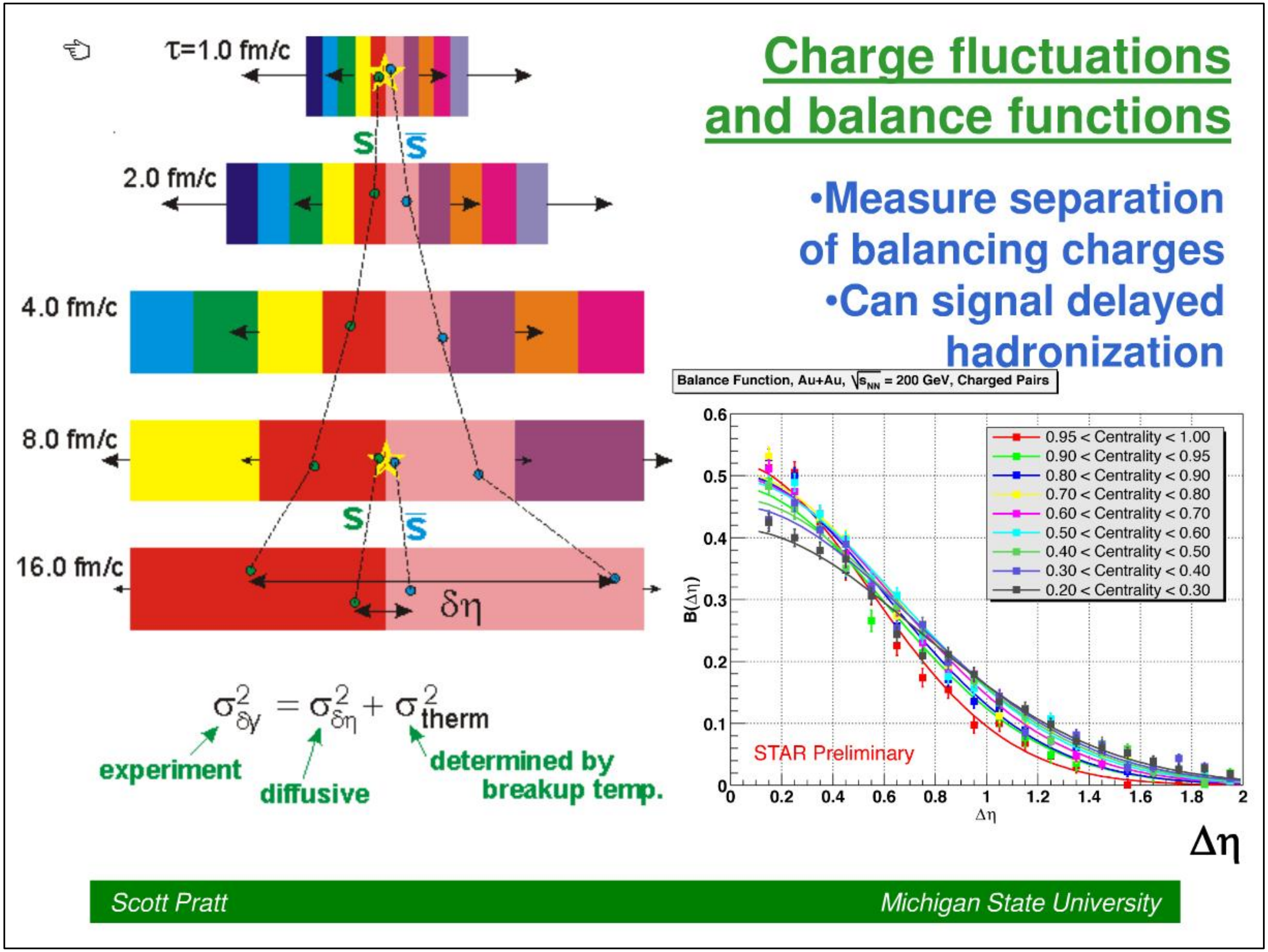
Weber, QM2012

Balance Function

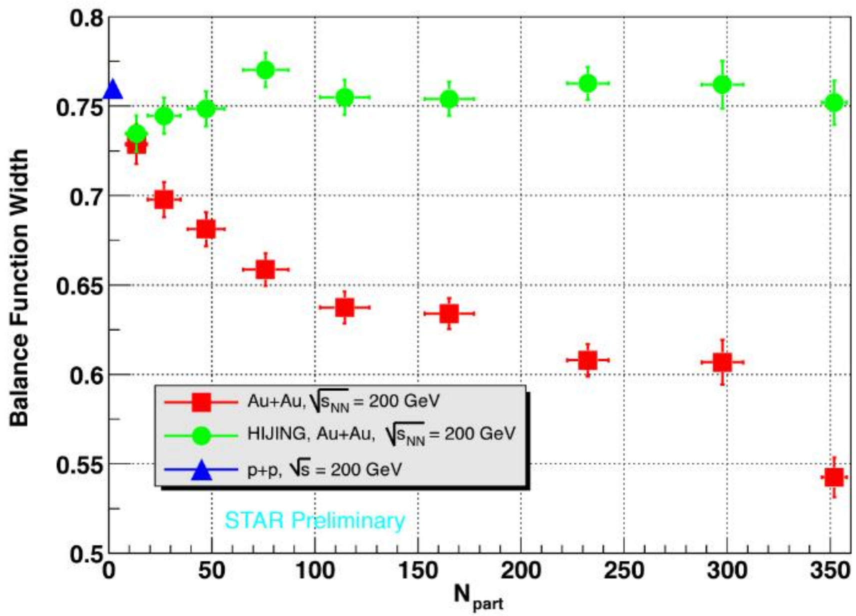


S. Pratt, QM2002

Balance Function

Charge fluctuations and balance functions

Balance Function Width



- Separation decreases with centrality
- Requires delayed production of charge (delayed hadronization)
- Suggests creation of gluon-rich matter

Scott Pratt *Michigan State University*

S. Pratt, QM2002

V_2 : incomplete NCQ scaling

QM 12 QuarkMatter

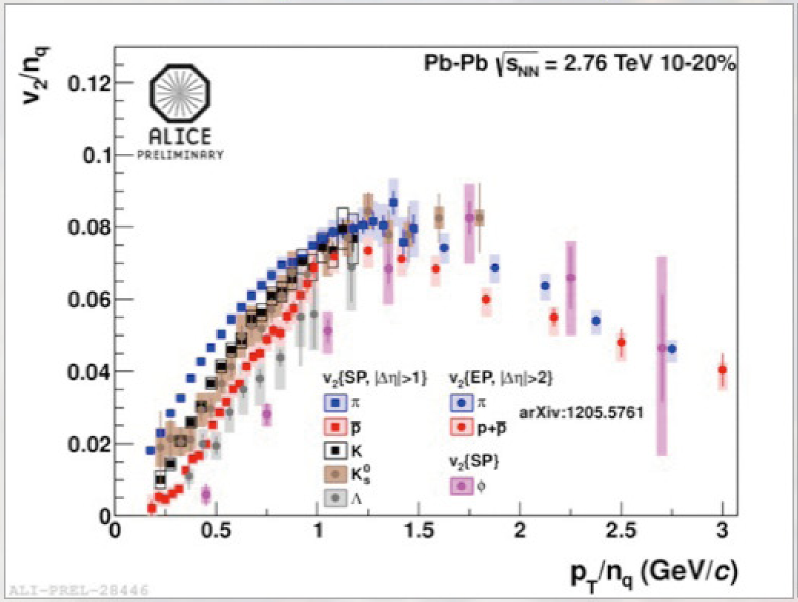
v_2 : quark number scaling(s)

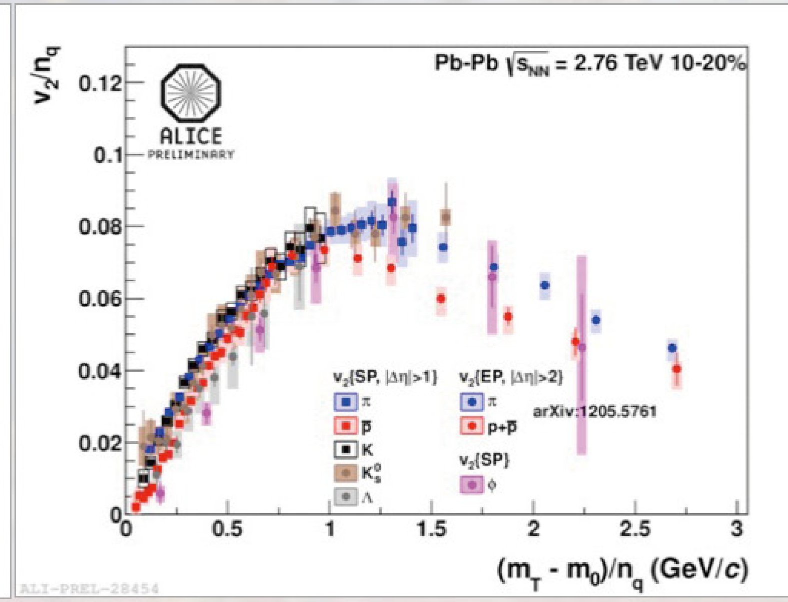
ALICE

Talk by F. Noferini

v_2/n_q vs p_T/n_q

v_2/n_q vs $(m_T-m_0)/n_q$





NCQ scaling: violation ~ 10% at p_T ~1.2 GeV/c

NQ (m_T) scaling: stronger violation vs RHIC.

For further discussion of the mass splitting and comparison with hydro, see talk by F. Noferini

Nonperturbative Gluonic Dynamics?

Bass, Müller, and M. A., arXiv 1208.2426

Nagoya Mini-Workshop 2012
"Phenomenology and Experiments at RHIC and LHC"
25-26 September 2012, Nagoya, Japan

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