The Effect of Dynamical Parton Recombination on Event-by-Event Observables

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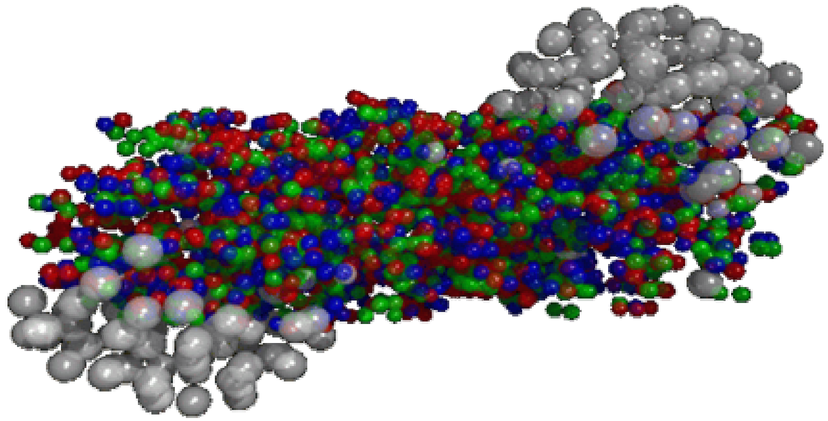


The Effect of Dynamical Parton Recombination on Event-by-Event Observables.
S. H., Stefan Scherer, Marcus Bleicher. e-Print: hep-ph/0702188

Thanks

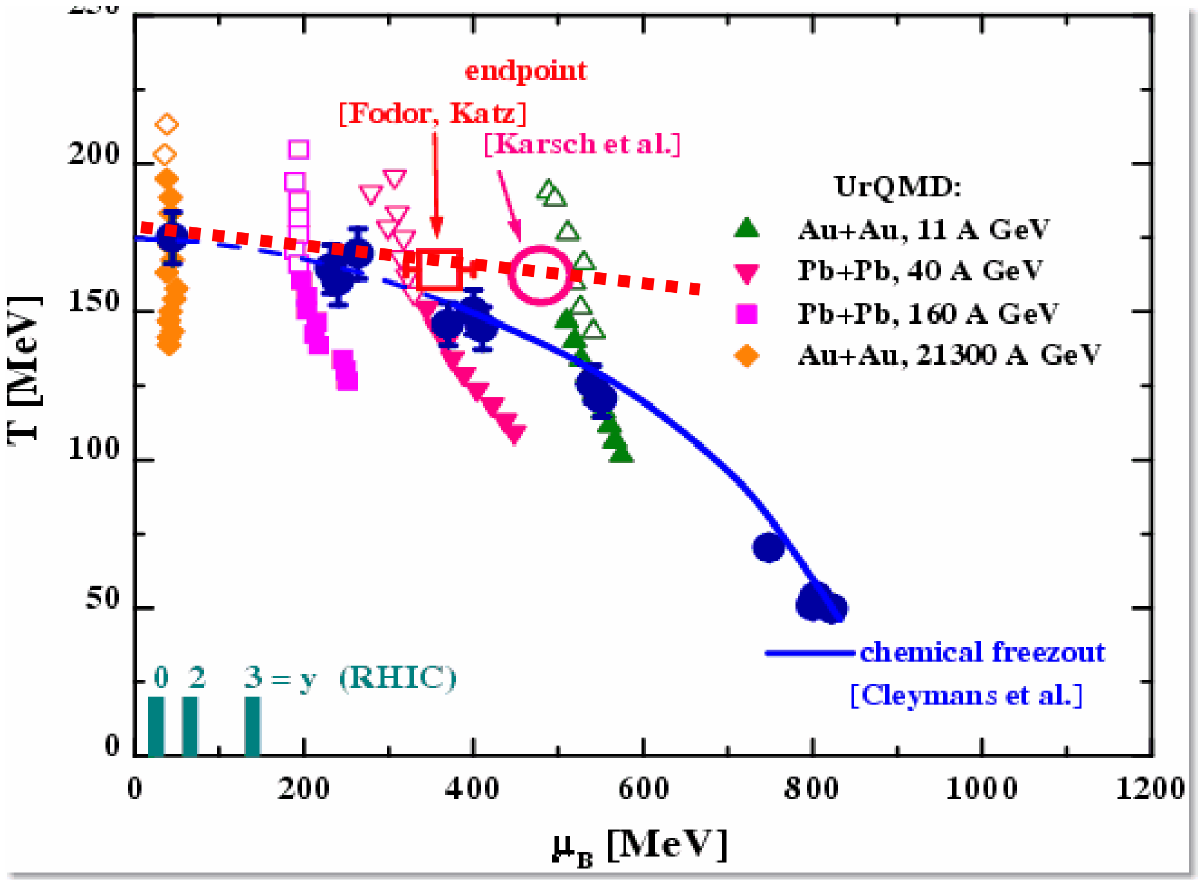
- Elena Bratkovskaya
- Manuel Reiter
- Sascha Vogel
- Xianglei Zhu
- Horst Stoecker
- Timo Spielmann

- Katharina Schmidt
- Hannah Petersen
- Stephane Haussler
- Daniel Krieg
- Benjamin Lungwitz

Outline of the talk

- Introduction
- The Quark-Molecular Dynamics
- Charge fluctuations
- Baryon-strangeness correlations
- Charge transfer fluctuations (see backup)
- Summary

Motivation



At **RHIC**:
look for signals of freely moving partons.
(D, C_{BS}, κ)

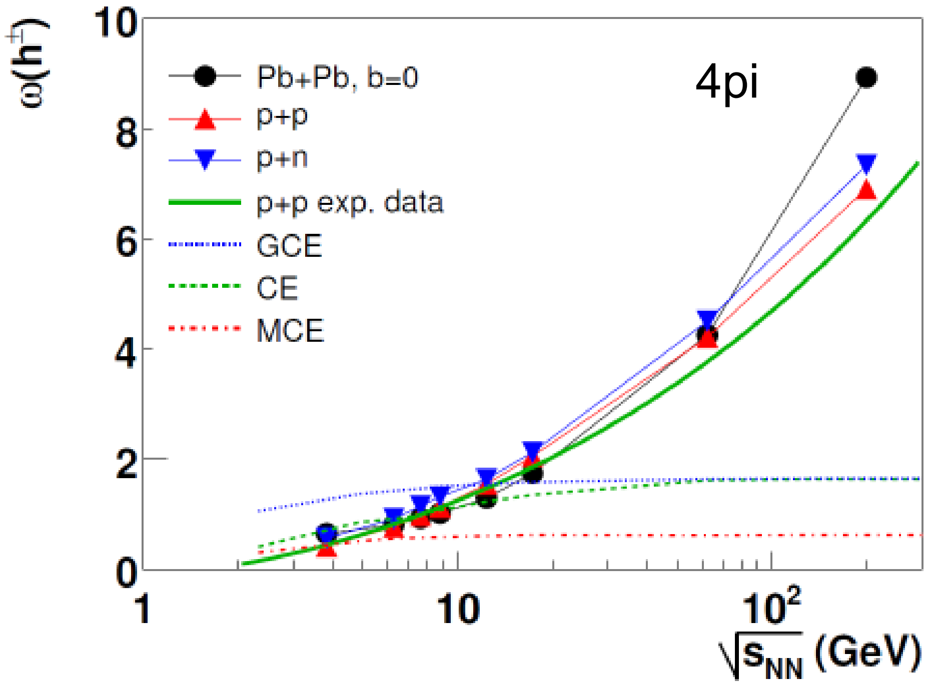
At **FAIR/SPS**:
look for the mixed phase and the onset of deconfinement
(ω, k/π, p/π)

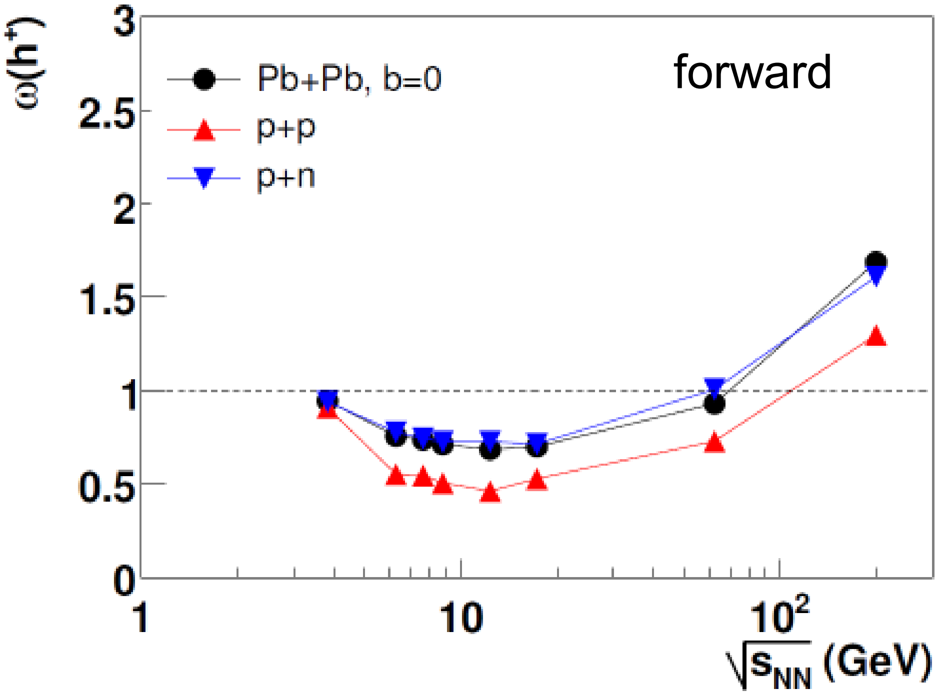
E. Bratkovskaya, M.B. et al., PRC 2005

Fluctuations are THE tool!?

- Fluctuations might provide information on
  - deconfinement/confinement
  - correlation length
  - thermalization
  - nature of the QGP
  - critical point
- Is it that easy?
  - finite time and volume
  - non-equilibrium
  - hadronization

Scaled variances





- Non-trivial structures

→Detailed non-equilibrium studies necessary

Lungwitz, Bleicher, in preparation

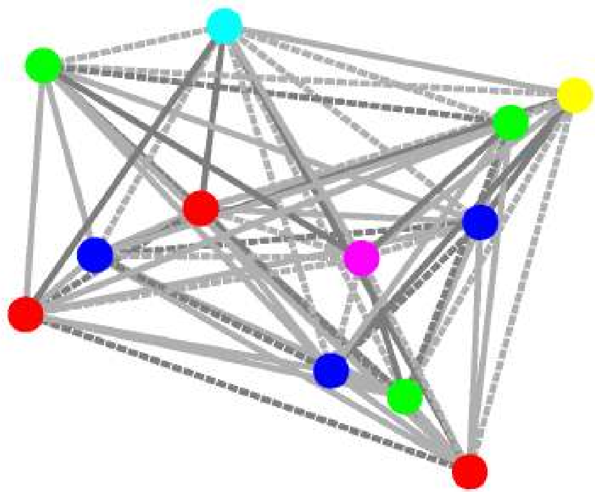
The tool: qMD

qMD : Quark Molecular Dynamics
(a toy model for hadronization)

- out-of-equilibrium transport model, (Vlasov equation)
- provides a hadronization prescription
- essentially realizes a dynamical quark recombination approach

Hofmann, Bleicher, Scherer, Neise, Stoecker, Greiner. Phys.Lett.B478:161-171,2000.

Quark Molecular Dynamics



Hamiltonian of the model :

$$H = \sum_{i=1}^{N} \sqrt{\mathbf{p}_i^2 + m_i^2} + \frac{1}{2} \sum_{i \neq j} C_{ij} V(|\mathbf{r}_i - \mathbf{r}_j|)$$

- Potential :

  linear potential $V(r) = \kappa r$

- Color factor C_{ij} :

  can be attractive or repulsive depending on the color of the quarks

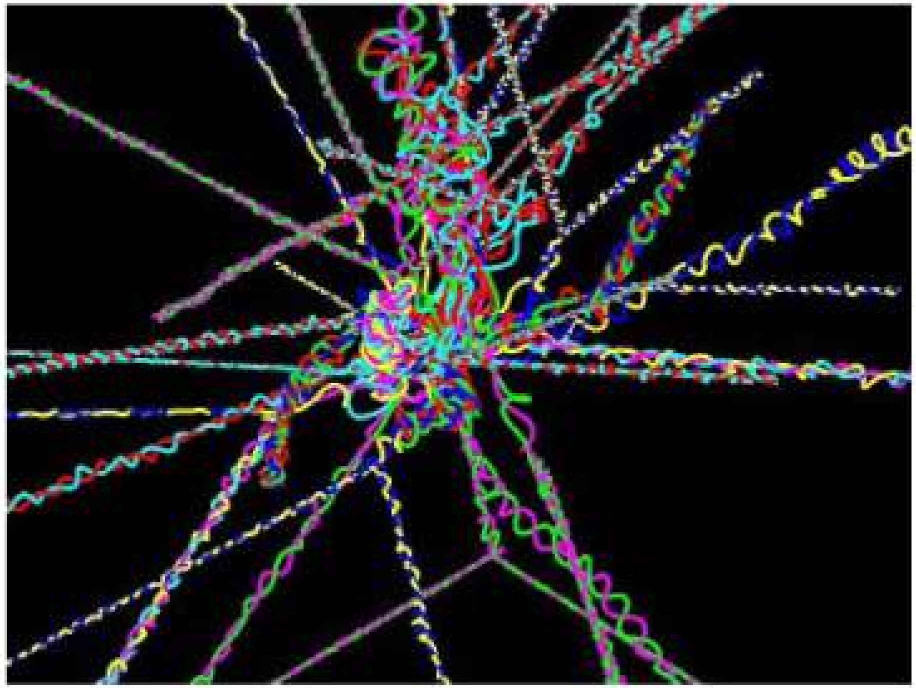
- Quarks :

  classical point-particles with light masses $m_{u,d} = 5$ MeV, $m_s = 150$ MeV

Trajectories

qMD features :

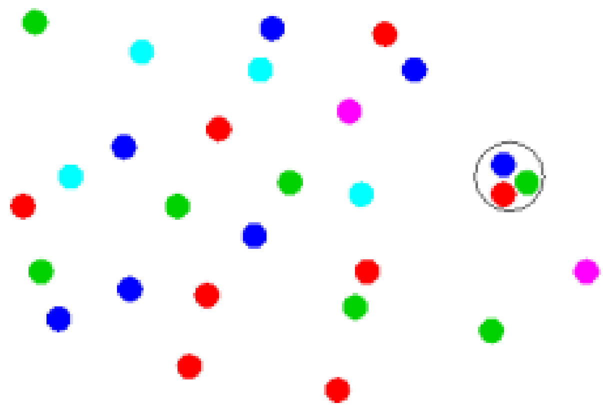
- mesons
- baryons
- confinement
- recombination
- out-of-equilibrium



M. Hofmann Ph.D. thesis

Hadronization procedure

- color neutral clusters
- separation in space
- small remaining interaction



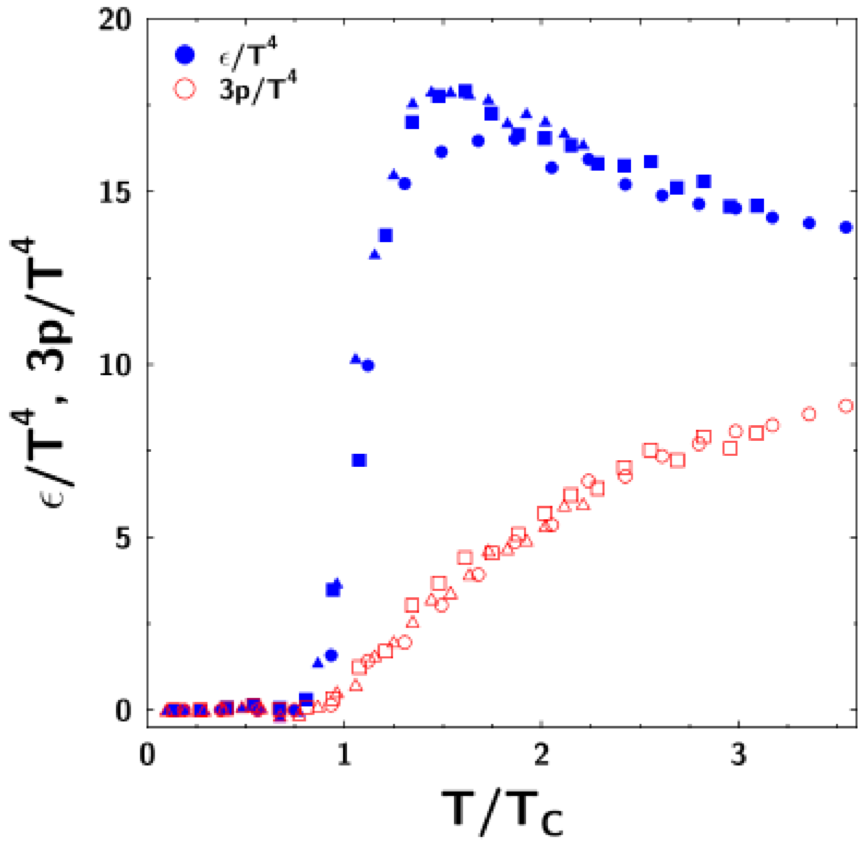
- force on quark i

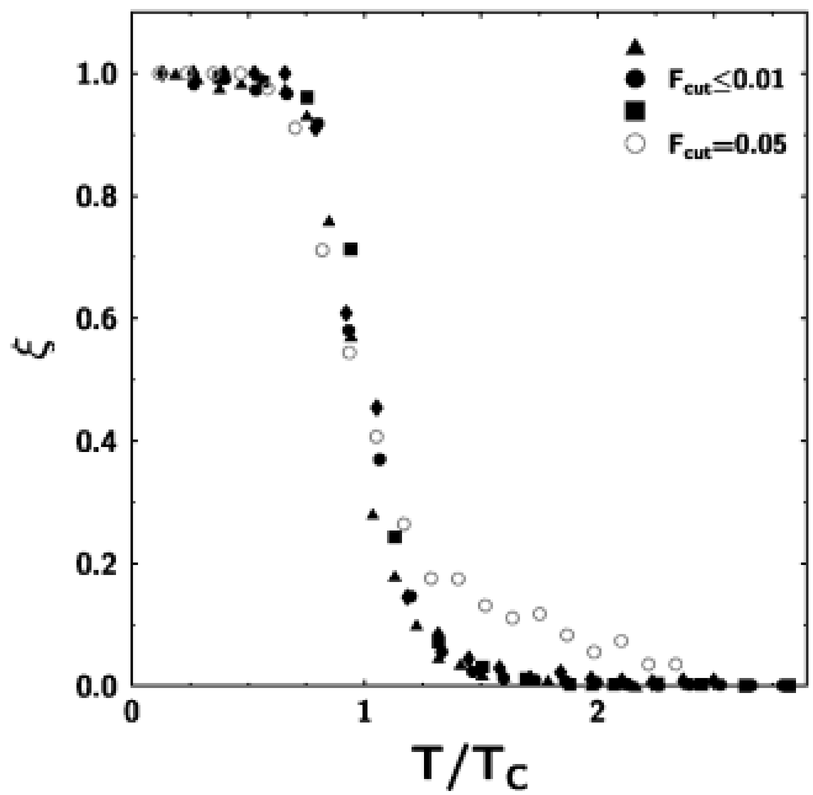
$$\vec{F}_i = \sum_j \vec{F}_{ij} = \sum_j C_{ij} \nabla_j V(|\vec{r}_i - \vec{r}_j|)$$

- Remaining interaction on a cluster

$$|\vec{F}_{cluster}| = |\frac{1}{N_{cluster}} \sum_{i \in cluster} \vec{F}_i| < \kappa_{min} = F_{cut}\ \kappa$$

Some properties: equilibrium

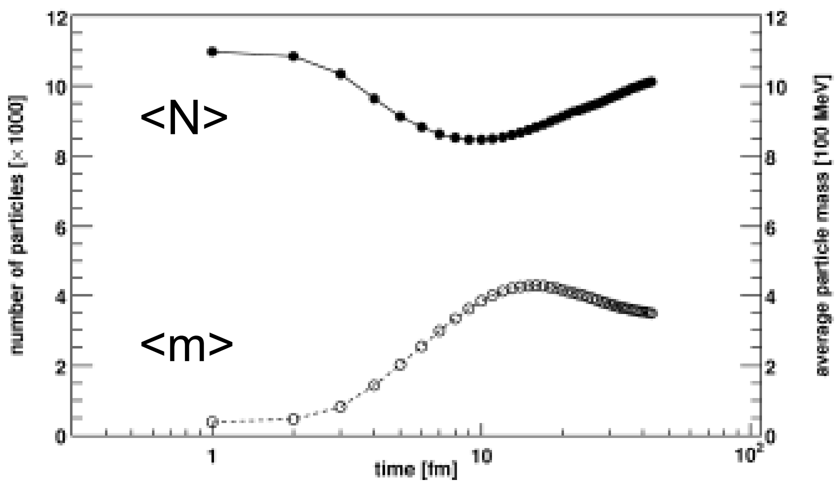




$$\xi = N_{hadrons} / N_{all\ \ particles}$$

- For ‘real’ physics use UrQMD initial state
- dissolve strings into ‘free’ quarks
- evolve system with qMD

Entropy consideration

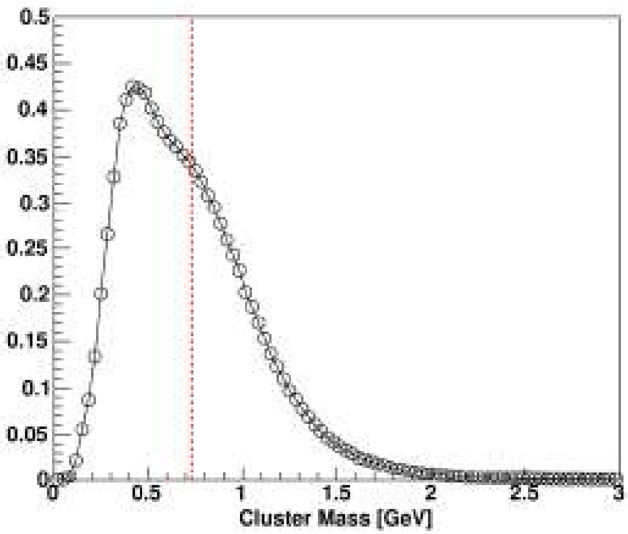


Do we violate the 2nd law of thermodynamics ?

- Entropy can be estimated by measuring the number of particles.
- As many particles at the begining and at the end of the calculation
- Heavy clusters will decay into numerous particles

The decay of resonance increases entropy

Entropy and recombination



Do we violate the 2^{nd} law of thermodynamics ?

- Entropy can be estimated by measuring the number of particles
- Without decay, the number of particles decreases at hadronization
- Entropy depends also on the mass of the particle
- for $m/T > 3$:

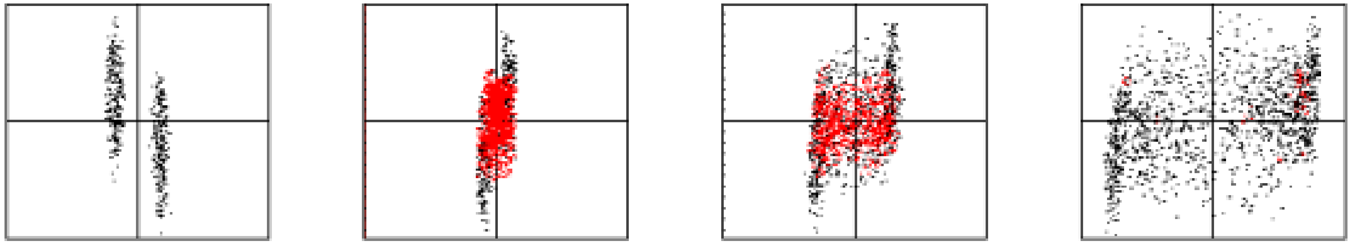
$$S/N = 3.5 + m/T$$

At the transition, $S_{QGP} < S_{HG}$

$$\begin{aligned} S_{QGP} &= 2\ N_{hadrons}\ 3.5 &&= 7\ N_{hadrons} \\ S_{HG} &= N_{hadrons}(3.5 + 750/150) &&= 8.5\ N_{hadrons} \end{aligned}$$

Recombination can be compatible with entropy conservation

The idea behind conserved charge fluctuations



Electric charge for example ($Q = Q_+ - Q_-$) :

Hadronic degrees of freedom :

$$i = (\pi^+, \pi^-)$$
$$Q_i = \pm 1$$

Partonic degrees of freedom :

$$i = (u, \bar{u}, d, \bar{d})$$
$$Q_i = \pm(\tfrac{1}{3}, \tfrac{2}{3})$$

$$\langle \delta Q^2 \rangle = \langle (\sum_i Q_i \delta N_i)^2 \rangle$$

Build quantities sensitive to the fractional charges of the partons

Fluctuations and suceptibilities

$$Z = \sum_i \exp[-\beta(E_i - \mu_Q Q_i - \mu_B B_i - \mu_S S_i)]$$

$$(X, Y) = (Q, B, S)$$

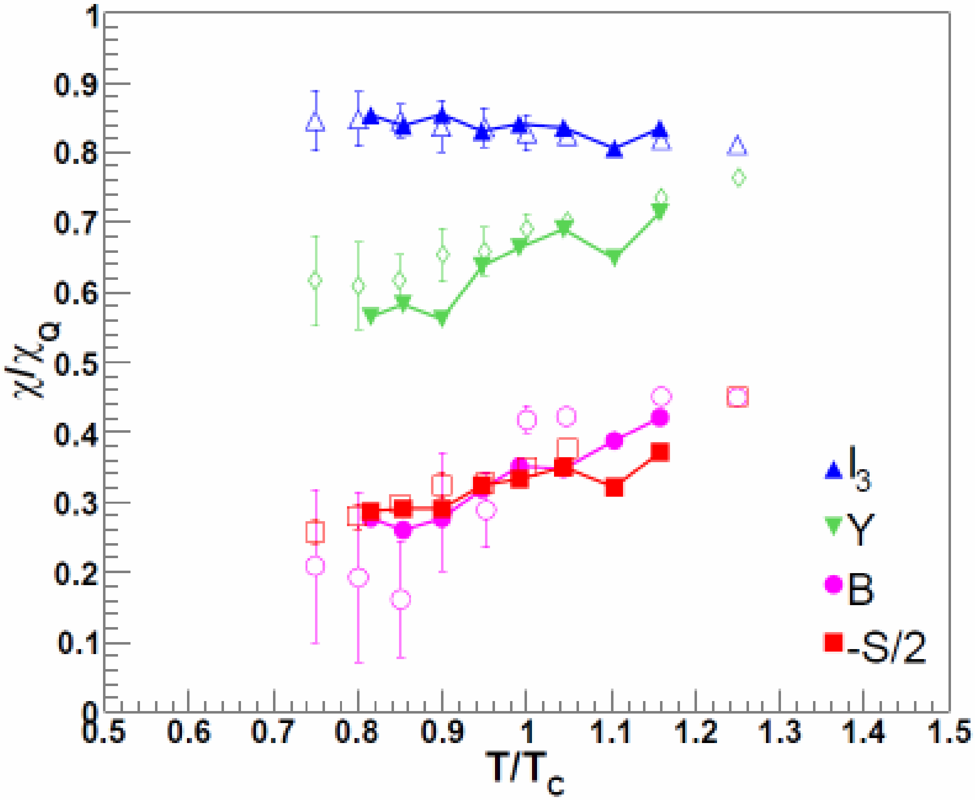
variances and correlations

$$\begin{aligned} \langle(\delta X)^2\rangle &= T^2 \frac{\partial^2}{\partial\mu_X^2}\log(Z) &= -T\frac{\partial^2}{\partial\mu_X^2}F \\ \langle(\delta X)(\delta Y)\rangle &= T^2 \frac{\partial^2}{\partial\mu_X\mu_Y}\log(Z) &= -T\frac{\partial^2}{\partial\mu_X^2\mu_Y^2}F \end{aligned}$$

susceptibilities

$$\begin{aligned} \langle\delta X^2\rangle &= -\frac{1}{V}\frac{\partial^2}{\partial\mu_X^2}F &= V\ T\ \chi_X \\ \langle\delta X\delta Y\rangle &= -\frac{1}{V}\frac{\partial^2}{\partial\mu_X\partial\mu_Y}F &= V\ T\ \chi_{XY} \end{aligned}$$

Comparison to lQCD (I)

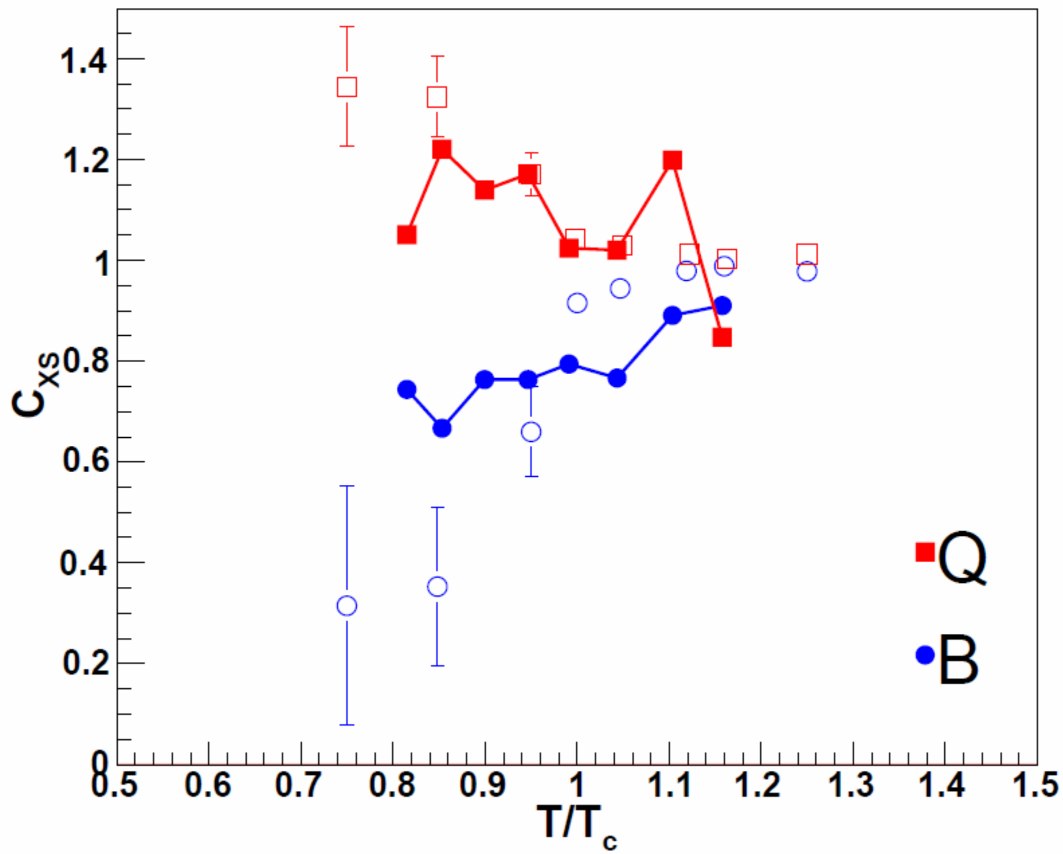


Open symbols : lattice data from Gavai, Gupta. Phys.Rev.D73:014004,2006

Full symbols with lines are the result of qMD calculations

$$\frac{\chi_{XQ}}{\chi_Q} = \frac{\langle XQ\rangle - \langle X\rangle\langle Q\rangle}{\langle Q^2\rangle - \langle Q\rangle^2}$$

Comparison to lQCD (II)



$$C_{BS} = -3\frac{\chi_{BS}}{\chi_S}$$

$$C_{QS} = 3\frac{\chi_{QS}}{\chi_S}$$

Open symbols : lattice data from Gavai, Gupta. Phys.Rev.D73:014004,2006

Full symbols with lines are the result of qMD calculations

- Hadron gas seems to be pretty similar to QGP…

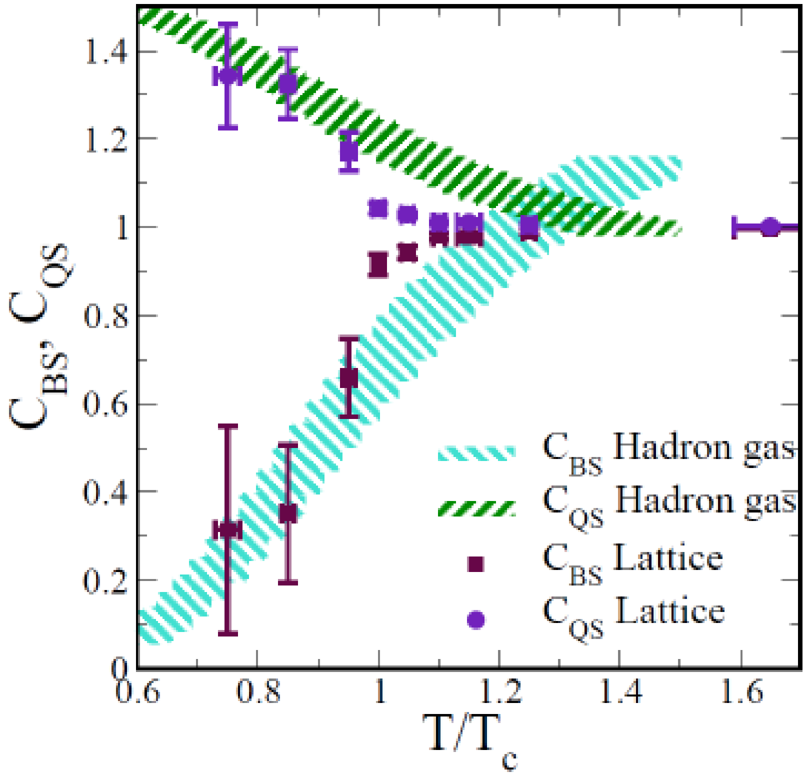


FIG. 3: (Color online) A comparison of the C_{BS} and C_{QS} calculated in a truncated hadron resonance gas at $\mu_B = \mu_S = \mu_Q = 0$MeV compared to lattice calculations at $\mu = 0$ from Ref. [22]. The two hazed bands for C_{BS} and C_{QS} for the hadron gas plots reflect the uncertainty in the actual value of the phase transition temperature T_c., which is assumed to lie in the range $T_c = 170 \pm 10$MeV.

(A. Majumder et al, Phys. Rev.C 74 (2006) 054901)

Charge ratio fluctuations

Jeon, Koch. Phys.Rev.Lett.85:2076-2079,2000.

Bleicher, Jeon, Koch. Phys.Rev.C62:061902,2000.

The Measure :

$$D = \langle N_{ch} \rangle \langle \delta R^2 \rangle$$

$$\begin{aligned} Q &= N_+ - N_- \\ N_{ch} &= N_+ + N_- \\ R &= N_+ / N_- \end{aligned}$$

$$D \approx 4 \frac{\langle \delta Q^2 \rangle}{\langle N_{ch} \rangle}$$

Corrections

$$\tilde{D}(\Delta y) = D(\Delta y) / (C_\mu \; C_y)$$

$$\begin{aligned} C_\mu &= \left(\frac{\langle N_+ \rangle_{\Delta y}}{\langle N_- \rangle_{\Delta y}} \right)^2 \\ C_y &= 1 - \frac{\langle N_{ch} \rangle_{\Delta y}}{\langle N_{ch} \rangle_{total}} \end{aligned}$$

Expectation values :

- $\tilde{D} = 1$ in a QGP
- $\tilde{D} = 4$ in an uncorrelated Pion Gas
- $\tilde{D} = 2.8$ in a Resonance Gas

$$D \approx 4\frac{\langle \delta Q^2 \rangle}{\langle N_{ch} \rangle}$$

$$\begin{aligned}
\delta Q &= \delta N_{\pi+} - \delta N_{\pi-} \\
(\delta Q)^2 &= \delta N^2_{\pi+} + \delta N^2_{\pi-} + correlations \\
\langle (\delta Q)^2 \rangle &= \langle \delta N^2_{\pi+} \rangle + \langle \delta N^2_{\pi-} \rangle \\
\langle (\delta Q^2) \rangle &= N_{\pi+} + N_{\pi-} = N_{ch}
\end{aligned}$$

Pion gas, D ~ 4

Assumptions :

$$\begin{aligned}
correlations &= 0 \\
\langle \delta N^2_{\pi+} \rangle &= \langle N_{\pi+} \rangle \\
\langle \delta N^2_{\pi-} \rangle &= \langle N_{\pi-} \rangle
\end{aligned}$$

$$\begin{aligned}
\delta Q &= Q_u(\delta N_u - \delta N_{\bar{u}}) + Q_d(\delta N_d - \delta N_{\bar{d}}) \\
\delta Q^2 &= Q_u^2(\delta N_u^2 + \delta N_{\bar{u}}^2) + Q_d^2(\delta N_d^2 + \delta N_{\bar{d}}^2) \\
&\quad + correlations \\
\langle \delta Q^2 \rangle &= Q_u^2 \langle N_{u+\bar{u}} \rangle + Q_d^2 \langle N_{d+\bar{d}} \rangle
\end{aligned}$$

$$D = 4\frac{Q_u^2 \frac{\langle N_{ch} \rangle}{2} + Q_d^2 \frac{\langle N_{ch} \rangle}{2}}{\langle N_{ch} \rangle}.$$

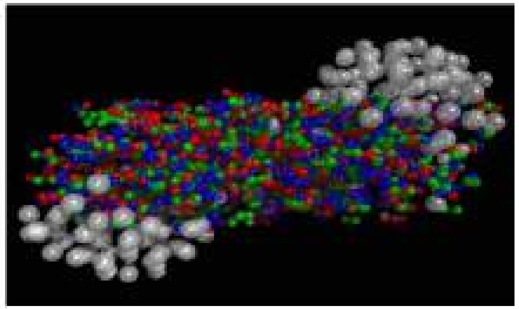
$$D = 4\frac{(1/3)^2 \frac{1}{2} + (2/3)^2 \frac{1}{2}}{1}.$$

Quark gas, D ~ 1

Assumptions :

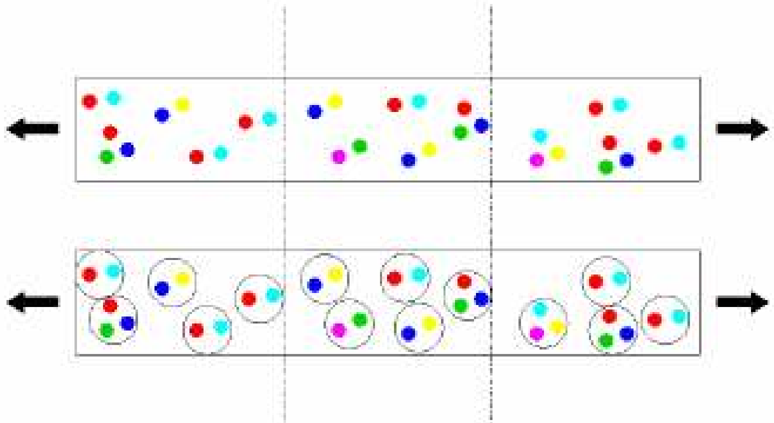
$$\begin{aligned}
correlations &= 0 \\
\langle \delta N_u^2 \rangle &= \langle N_u \rangle \\
\langle \delta N_d^2 \rangle &= \langle N_d \rangle \\
\langle N_{u+\bar{u}} \rangle &= \langle N_{ch} \rangle / 2 \\
\langle N_{d+\bar{d}} \rangle &= \langle N_{ch} \rangle / 2 \\
\langle N_{ch} \rangle &= \langle N_{q+\bar{q}} \rangle
\end{aligned}$$

Can one observe the fluctuations in the initial state?



Longitudinal flow

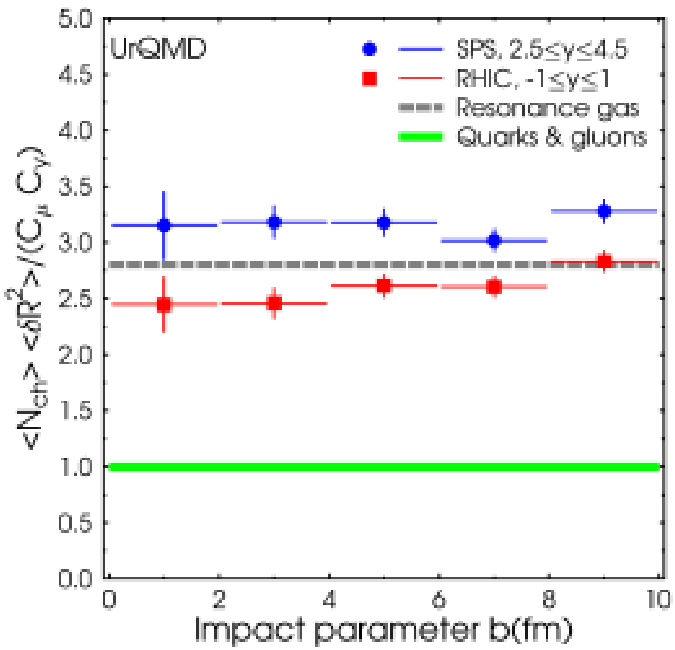
- Initial fluctuations should be frozen in a given rapidity window
- Different studies show that rescattering is not sufficient to dampen the signal
- $\Delta y_{kick} \ll \Delta y_{accept} \ll \Delta y_{total}$
- A key point is the influence of hadronization

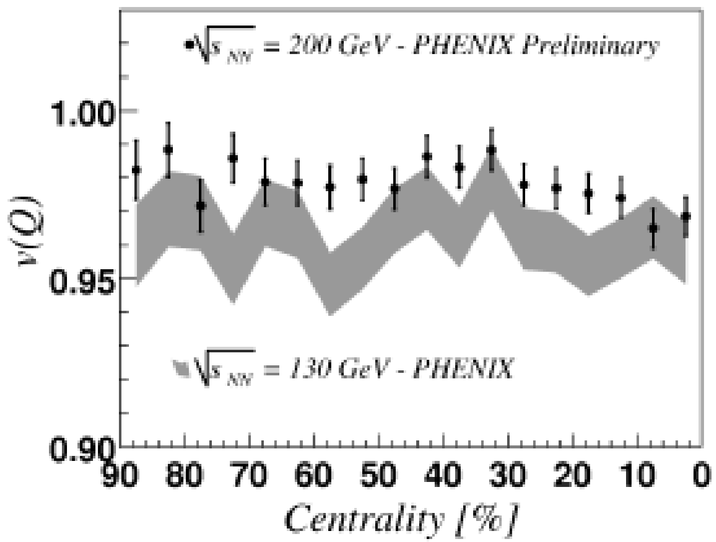


See e.g. Shuryak et al, Phys.Rev.C63:064903,2001

Experimental results

Bleicher, Jeon, Koch. Phys.Rev.C62:061902,2000

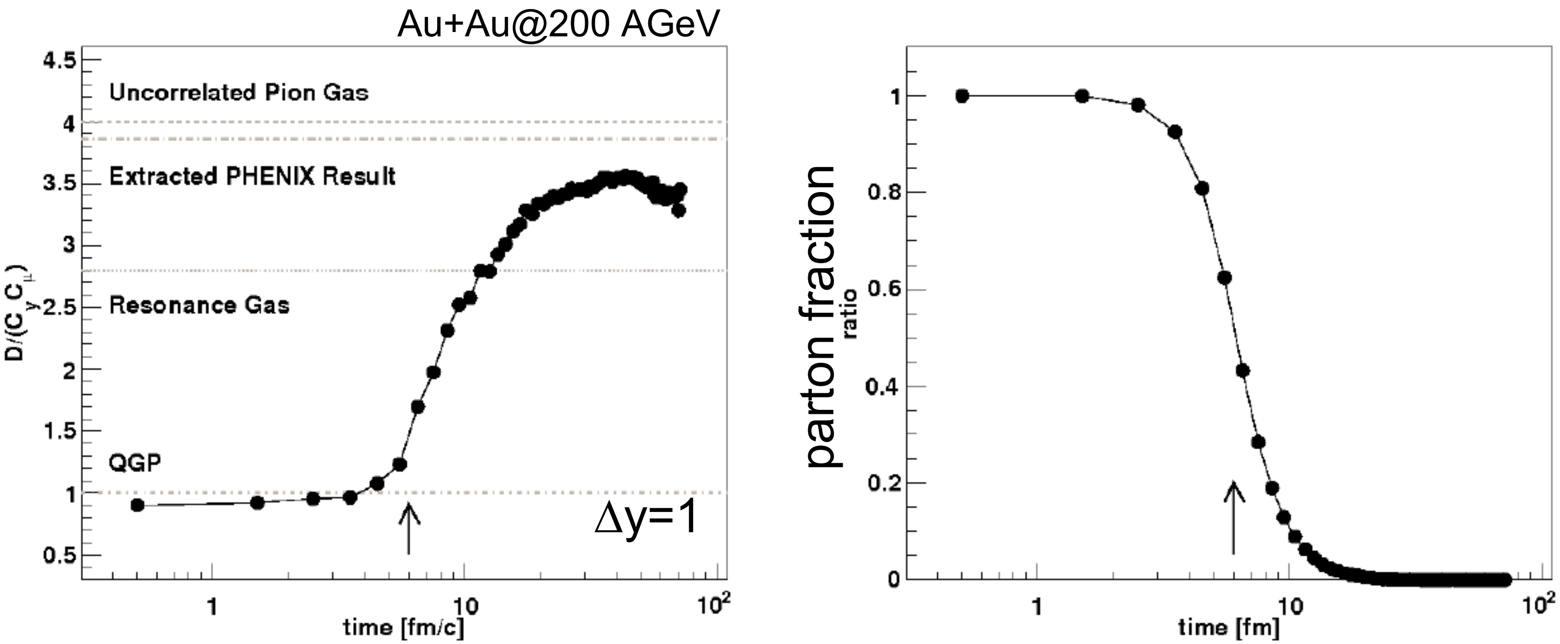




$$\tilde{D} = \frac{\langle N_{ch} \rangle \langle \delta R^2 \rangle}{C_\mu \ C_y} \approx 4 \ \nu(Q)$$

Compatible with the hadronic expectation

Recombination and fluctuation



Recombination kills the fluctuations

- $\tilde{D} = 1$ in the quark matter phase
- $\tilde{D}$ is compatible with the experiment result in the late stage
- Hadronization and the increase of $\tilde{D}$ occur at the same time

See also…

- Bialas: Recombination blur ratio fluctuations (Phys.Lett.B532:249-251,2002)
- Nonaka: Recombination blurs ratio fluctuations (Phys.Rev.C71:051901,2005)
- Ma: Hadronization blurs ratio fluctuations (SQM 2007)
- Present work:

The Effect of Dynamical Parton Recombination on Event-by-Event Observables.
S. H., Stefan Scherer, Marcus Bleicher. e-Print: hep-ph/0702188

Baryon-Strangeness Correlations

Koch, Majumder, Randrup. Phys.Rev.Lett.95:182301,2005.
S. H., Stoecker, Bleicher. Phys.Rev.C73:021901,2006.

In a QGP, strangeness is always carried together with baryon number
In a Hadron Gas, Strangeness can be carried without baryon number

$$C_{BS} = -3\frac{\langle BS\rangle - \langle B\rangle\langle S\rangle}{\langle S^2\rangle - \langle S\rangle^2} \approx -3\frac{\langle BS\rangle}{\langle S^2\rangle}$$

expectation values :

- $C_{BS} = 1$ in a QGP
- $C_{BS} = 0.66$ in a HG ($T = 170$ MeV, $\mu = 0$)

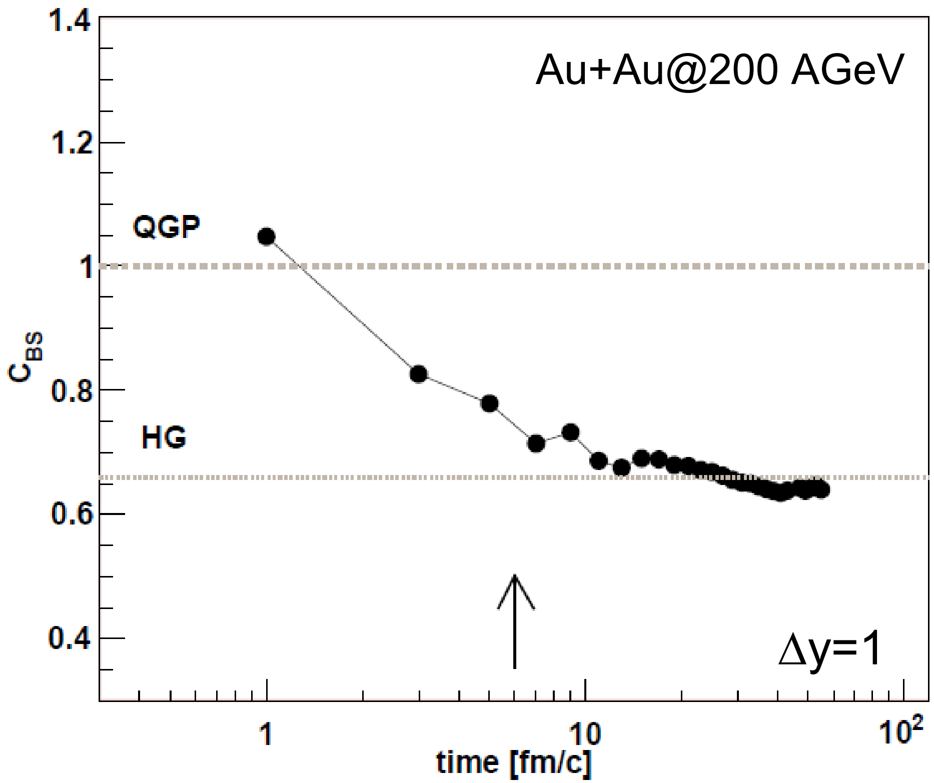
related quantities :

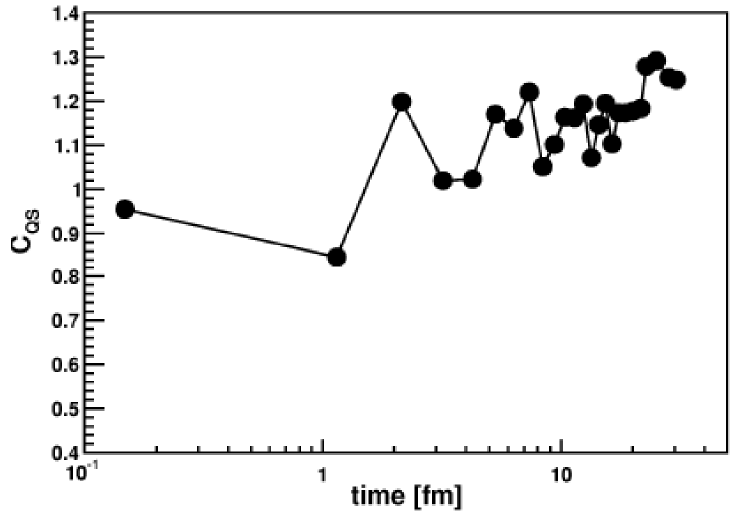
some particles are difficult to measure

- $C_{QS} = \frac{\langle QS\rangle - \langle Q\rangle\langle S\rangle}{\langle S^2\rangle - \langle S\rangle^2} \approx \frac{3 - C_{BS}}{2}$
- $C_{MS} \approx C_{BS}$ with $M = B + 2I_3$
- take into account only strange charged particles

Time evolution

The signal vanishes with hadronization for all these quantities

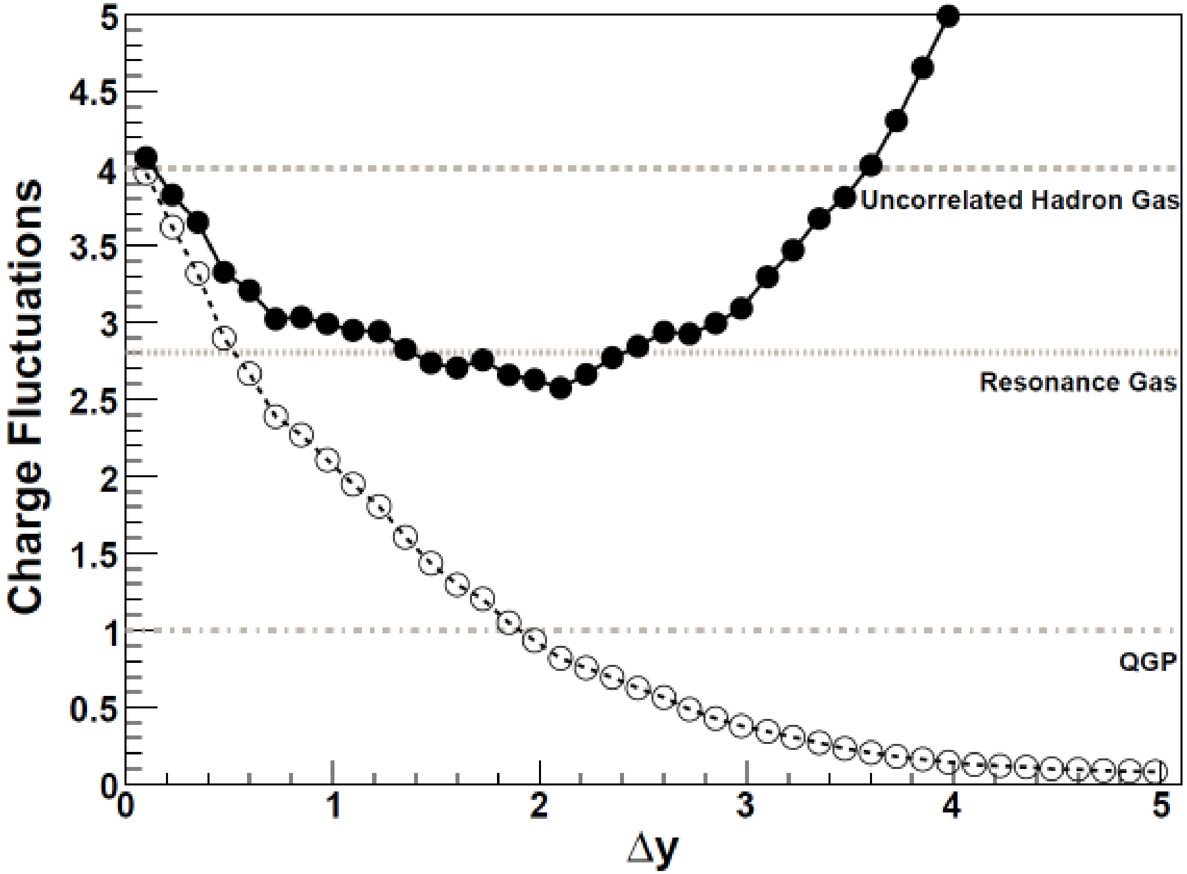




Conclusions

- qMD performs dynamical recombination to describe the hadronization of quarks into hadrons
- charge fluctuations were measured in different experiment and yield the hadron-gas expectation
- C_{BS} was measured on the lattice and yield the expected QGP result
- recombination kills all "smokin' gun" signals related to the fluctuations and correlations of conserved charges
- conversely, the agreement with experimental results can be seen as another evidence for recombination

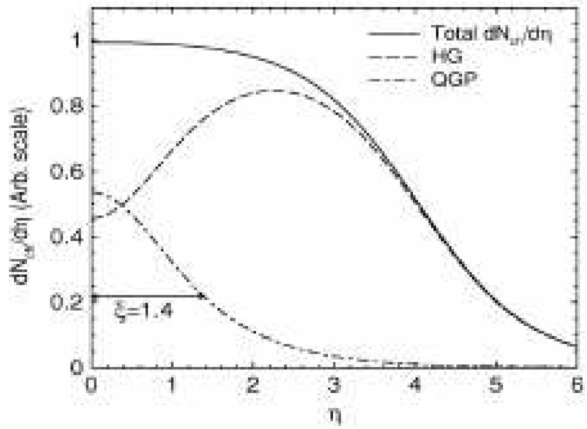
Additional slides

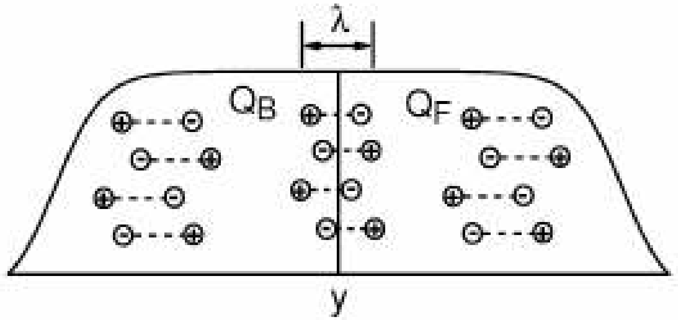


Charge Fluctuations
Δy
Uncorrelated Hadron Gas
Resonance Gas
QGP
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1
2
3
4
5

Charge transfer fluctuations

Shi, Jeon. Phys.Rev.C72:034904,2005
Jeon, Shi, Bleicher. Phys.Rev.C73:014905,2006



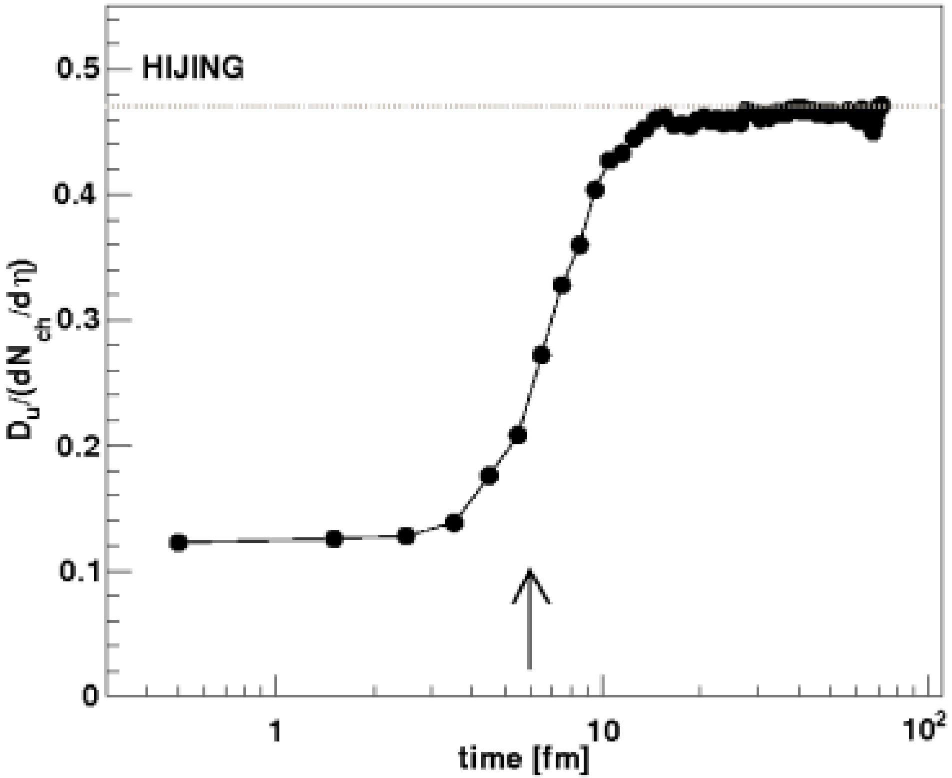


Idea

- $D_u(\eta) = \langle u(\eta)^2 \rangle - \langle u(\eta) \rangle^2$
- $u(\eta) = [Q_F(\eta) - Q_B(\eta)]/2$
- $\kappa(y) = \frac{D_u(y)}{dN_{ch}/dy}$
- κ is proportional to the charge correlation length

qMD results on kappa

calculate $\frac{D_u(y)}{dN_{ch}/dy}$ at midrapidity where the signal should be the strongest



Au+Au@200 AGeV