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Parton Recombination And Fluctuations Of Conserved Charges

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We study various fluctuation and correlation signals of the deconfined state using a dynamical recombination approach (quark Molecular Dynamics, qMD). We analyse charge ratio fluctuations, charge transfer fluctuations and baryon-strangeness correlations as a function of the center of mass energy with a set of central Pb+Pb/Au+Au events from AGS energies on ($E_{lab} = 4$ AGeV) up to the highest RHIC energy available ($\sqrt{s_{NN}} = 200$ GeV) and as a function of time with a set of central Au+Au qMD events at $\sqrt{s_{NN}} = 200$ GeV with and without applying our hadronization procedure. For all studied quantities, the results start from values compatible with a weakly coupled QGP in the early stage and end with values compatible with the hadronic result in the final state. We show that the loss of the signal occurs at the same time as hadronization and trace it back to the dynamical recombination process implemented in our model.

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1. introduction

Numerous physical quantities indicate that a plasma of deconfined quarks and gluons is created in the highly excited and dense nuclear matter created in ultra-relativistic heavy ion collisions at sufficiently high energies. Among them, fluctuation studies have been proposed as a tool to disentangle the properties of the matter created in the course of the collision and pin down the existence of the QGP [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29]. Fluctuations of conserved charges in particular are sensitive to the unit of charge of the matter and should lead to different fluctuations depending whether the expanding fireball went through a QGP phase or not. Charge ratio fluctuations, charge transfer fluctuations and baryon-strangeness correlations were prominently proposed to probe the deconfined phase at RHIC [30, 12, 31, 32, 33, 20, 21, 22, 23, 24, 25, 34]. It was pointed out that these quantities should reflect the properties of the system in the first instant of the collision and survive the whole evolution of the system because the longitudinal expansion is too fast for the initial partonic fluctuations to relax through hadronic rescattering in a given rapidity slice. However, no signal of the QGP has been seen in the available experimental data on fluctuations to date.

A crucial point might be the influence of hadronization on the fluctuations of conserved charges that could relax the initial state fluctuations to their hadronic value at the partonic/hadronic transition. The recombination of quarks into hadrons [35, 36, 37, 38, 39, 40, 41] is a possible mechanism to treat hadronization. Experimentally, the number of constituent quarks scaling of the elliptic flow v_2 [42, 37] and the large number of baryons over number of mesons ratio in the intermediate p_t range measured in central Au+Au collisions at RHIC energies [40, 41, 43] can be well understood in the recombination picture.

In this paper, we use the quark Molecular Dynamics (qMD) model [44, 45, 46, 47] that performs the recombination of quarks dynamically in an expanding medium and aims at describing the partonic/hadronic transition and the properties of matter in the vicinity of the critical temperature. In previous studies [20, 48] performed with qMD and in an earlier exploratory work [49, 50], it was argued that recombination should lead to a complete vanishing of various initial state QGP fluctuations/correlations signals. Further work on baryon-strangeness correlations where hadronization is performed through the recombination of quarks also points out a drastic influence of the (recombination-)hadronization mechanism [51].

This article is organized as follow : We first introduce the quark Molecular Dynamics (qMD) model employed for this study. We then study various correlations/fluctuations of conserved charges signals, namely charged particles ratio fluctuations, charge transfer fluctuations and baryon-strangeness correlations. We argue that the recombination-hadronization procedure used in the qMD model is responsible for the loss of the signal in the final state, thus indicating a drastic influence of (recombination-)hadronization on all these signals.

2. The qMD model

The qMD model [44, 45, 46, 47] employed here is a semi-classical molecular dynamics approach where quarks are treated as point-like particles carrying color charges and interact via a

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linear heavy quark potential. Initial conditions [1] for the qMD are taken from the hadron-string transport model UrQMD [52, 53] : After the two incoming nuclei have passed through each other, (pre-) hadrons from the strings and fully formed hadrons of the UrQMD model are decomposed into quarks with current masses $m_u = m_d = 5$ MeV and $m_s = 150$ MeV. At the highest RHIC energy, this happens at a center of mass time of $t = 0.15$ fm/c. The quarks are then let to evolve and interact within the qMD via the heavy quark potential $V(|\mathbf{r}_i - \mathbf{r}_j|) = \kappa|\mathbf{r}_i - \mathbf{r}_j|$, where κ is the string tension and $\mathbf{r}_n$ is the position of particle n. Therefore the full Hamiltonian of the model reads :

$$H = \sum_{i=1}^{N} \sqrt{p_i^2 + m_i^2} + \frac{1}{2} \sum_{i,j} C_{ij} V(|\mathbf{r}_i - \mathbf{r}_j|) \quad . \tag{2.1}$$

Where N counts the number of particles in the system and the term C_{ij} takes into account the color dependence of the interaction.

The quark–(anti-)quark interaction within this potential naturally leads to confinement through the binding of (anti-)quarks into color neutral clusters. New hadrons are formed from quarks whose momentum and positions are close to each others. Typical values for the relative momenta of the quarks in the two-particle rest frame at hadronization are $|p_q| = |p_{\bar{q}}| \leq 500$ MeV, the typical distance is below 1 fm. Hadronization thus occurs locally into hadronic clusters of mesonic and baryonic type that resembles the Yo-Yo states of the LUND model. These clusters are then mapped to known hadrons and resonances that are later allowed to decay in the further evolution of the system. The reader is referred to [44, 45, 46, 47] for a detailed discussion of the qMD model. In the present calculations, u, d and s quarks are included and all parton production occurs in the early stage of the reaction during the UrQMD evolution. There is no further production of new (di-)quark pairs during the qMD evolution stage. Thus, the present model provides an explicit recombination transition from quark matter to hadronic matter in a dynamical and expanding medium. Due to the employed inter-quark potential, confinement is a natural feature of the qMD model. Being color neutral at the beginning of the calculations, the system is also color neutral at the end of the simulations and all quarks of the original QGP system will ultimately recombine into hadrons.

The so-formed clusters are mapped to known hadrons or resonance states according to the quantum numbers of the partons. It is further required that the total force $\overrightarrow{F}_{cluster}$ of the remaining system on the cluster is small. A color neutral cluster interacts with the rest of the system according to :

$$|\overrightarrow{F}_{cluster}| = |\frac{1}{N_{cluster}} \sum_{i \in cluster} \overrightarrow{F}_i| \tag{2.2}$$

Where we sum the forces $\overrightarrow{F}_i$ of the system on each $N_{cluster} = (2,3)$ quarks forming the cluster. The force of the whole system on a specific quark i derives from the potential interaction computed for all possible quarks combinations :

$$\overrightarrow{F}_i = \sum_j \overrightarrow{F}_{ij} = \sum_j C_{ij} \nabla_j V(|\overrightarrow{r}_i - \overrightarrow{r}_j|) \tag{2.3}$$

[1] It should be noted that the qualitative results of the present study are not restricted to any specific initial state. The UrQMD model is solely used to provide an exemplary initial state after the initial $q\bar{q}$ production has taken place.

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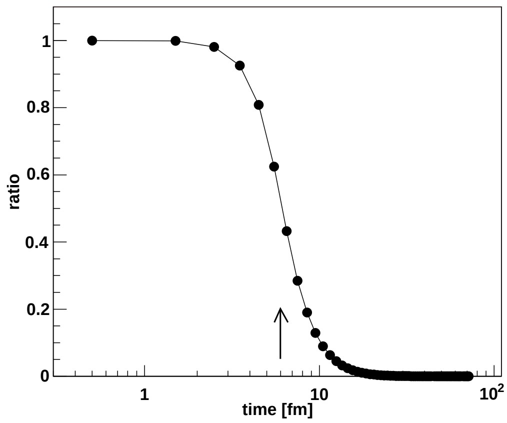

Figure 1: Fraction of the number of quarks from the total number of particles as a function of time at midrapidity for Au+Au reactions at $\sqrt{s_{NN}} = 200$ GeV. The arrow depicts the hadronization time.

There is a small remaining interaction between a cluster and the rest of the system, taken into account in the mass of the formed hadron in order to fulfill energy conservation. Thus, we allow the formation of a new hadron when the cluster is well separated in coordinate space with the rest of the system and when the remaining interaction is small :

$$|\overrightarrow{F}_{cluster}| =< \kappa_{min} = F_{cut}\ \kappa \tag{2.4}$$

where κ is the string tension and F_{cut} is a parameter of the model.

Most of the mass of the newly formed hadrons comes from the potential energy between the quarks forming the considered cluster. Generally, clusters with large masses are mapped to heavy hadronic resonances that are later allowed to decay. Note that the mapping procedure can be turned off to disentangle the effect of hadronization on the various fluctuations probes studied here. Quarks will still gather into colour neutral clusters due to the binding inter-quark potential, but are not mapped to hadrons. Also, note that the hadronic rescattering stage is neglected in the present work.

3. Fluctuations of conserved charges

Let us set the stage by exploring the time evolution of the hadronization dynamics in the model with a set of central Au+Au event at $\sqrt{s} = 200$ AGeV. Fig. 1 depicts the fraction of quark matter on the total number of particles in the system, i.e. quark fraction $= (n_q + n_{\bar{q}})/(n_{\text{hadron}} + n_q + n_{\bar{q}})$ as a function of time. With the given initial conditions, the fireball stays in a deconfined state during the first 6 fm/c where almost no quarks hadronize. As the system expands further and density decreases, quark recombination into baryons and mesons occurs and the number of deconfined quarks drops to zero. The point at which the parton-hadron transition occurs will be denoted by arrows in the following plots. We now turn to the investigation of the various fluctuation signals.

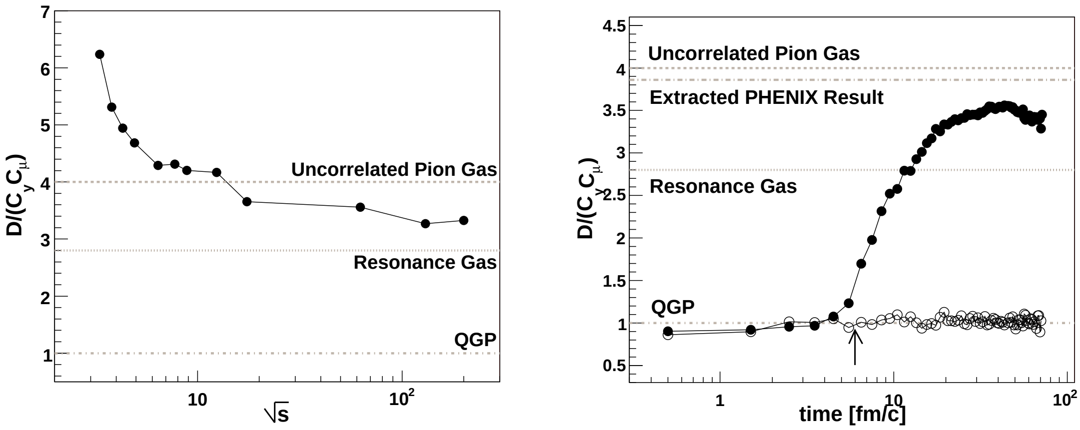

Figure 2:
Left : Charge ratio fluctuations $\tilde{D}$ calculated with a set of central Au+Au/Pb+Pb qMD events as a function of $\sqrt{s_{NN}}$. The rapidity window is $y_{\max} = 0.5$.
Right : Charge fluctuations $\tilde{D}$ as a function of time within the qMD model for Au+Au reaction at $\sqrt{s_{NN}} =$ 200 GeV. Full symbols are the results of a full qMD calculation. Open symbols are the result of a qMD calculation where the mapping procedure is not applied (see text for details). Also shown are the values for an uncorrelated pion gas, a resonance gas and a quark-gluon plasma. The arrow depicts the hadronization time.

3.1 Charge Ratio Fluctuations

The electric charge ratio fluctuations were proposed as a clear signal for the onset of the quark-gluon plasma phase [30]. The basis for the argument is that the quanta of the electric charge carrier are smaller in a quark gluon plasma phase than in a hadron gas and are distributed over a larger number of particles. Moving one charged particle from/to the rapidity window then leads to larger fluctuations in a hadron gas than in a QGP. The electric charge ratio fluctuation can be quantified by the measure $\tilde{D}$ defined as:

$$\tilde{D} = \frac{1}{C_\mu C_y} \langle N_{ch} \rangle \langle \delta R^2 \rangle_{\Delta y} \quad . \tag{3.1}$$

Where N_{ch} stands for the number of charged particles, $R = (1+F)/(1-F)$ with $F = Q/N_{ch}$, Q being the electric charge. Following [13], charge particle ratio fluctuations D is divided by the factors C_μ to correct for finite net charge due to baryon stopping and C_y for global charge conservation correction. As suggested in [30, 13], the quantity $\tilde{D}$ is calculated in a rapidity window of $y = \pm 0.5$. It was argued that depending on the nature of the initial system, $\tilde{D}$ will yield distinctly different results : $\tilde{D} = 1$ for a quark-gluon plasma, $\tilde{D} = 2.8$ for a resonance gas and $\tilde{D} = 4$ for an uncorrelated pion gas.

Experimentally, charge ratio fluctuations have been measured at RHIC energies by STAR [54, 55] and PHENIX [56, 57]. Both experimental analyses yield results compatible with a hadron gas. Further results from CERN-SPS [58, 59] based on a slightly different measure for the charge ratio fluctuations are also compatible with the hadronic expectation.

Charge ratio fluctuations $\tilde{D}$ as a function of the center of mass energy $\sqrt{s_{NN}}$ calculated within a sample of central Pb+Pb/Au+Au events is depicted on Fig. 2 (Left). $\tilde{D}$ is compatible with the expectation value calculated in [13] for a simple uncorrelated pion gas at high energy and increases with decreasing energy when reaching the baryon-rich sector with $\mu_B > 0$ at low SPS energies and below. In the whole energy range scanned within our partonic/hadronic recombination model, $\tilde{D}$ stays well above the QGP expectation result even at the highest RHIC energy ($\sqrt{s_{NN}} = 200$ GeV) where the system stays in the deconfined phase for 6 fm/c as shown on Fig. 1.

Fig. 2 (Right) shows the result for $\tilde{D}$ from the qMD recombination approach as a function of time. Full symbols depict the qMD result for a full qMD calculation where the mapping procedure and subsequent decay of heavy resonance is applied. In the early stage, when the system is completely in the deconfined phase, $\tilde{D} \approx 1$ as expected. When approaching the hadronization time, $\tilde{D}$ starts to increase and reaches $\tilde{D} \approx 3.5$ after hadronization. The increase of $\tilde{D}$ occurs exactly at the same time as the recombination of the quarks and anti-quarks into hadrons. The slight decrease of $\tilde{D}$ at later times is related to the continuing decay of resonances [6] lowering the charge ratio fluctuations. Open symbols are the result of qMD calculations where quarks are not mapped to hadrons after having formed pre-hadronic correlations and are let to evolve according to the Hamiltonian of equation Eq. 2.1 without hadronization (i.e. a change in the degrees of freedom). $\tilde{D}$ stays at the QGP value and does not increase to the hadron gas value.

3.2 Charge Transfer Fluctuations

As a next observable, we now turn to charge transfer fluctuations that were also suggested to provide insight about the formation of a QGP phase. Charge transfer fluctuations are a measure of the local charge correlation length. They are defined as [20, 21, 22, 23] :

$$D_u(\eta) = \langle u(\eta)^2 \rangle - \langle u(\eta) \rangle^2 \quad , \tag{3.2}$$

with the charge transfer $u(\eta)$ being the forward-backward charge difference:

$$u(\eta) = [Q_F(\eta) - Q_B(\eta)]/2 \quad , \tag{3.3}$$

where Q_F and Q_B are the charges in the forward and backward hemisphere of the region separated at $\eta = 0$. In our calculations, we take a total window of $y = \pm 1$, corresponding to the STAR acceptance. Experimental data on this observable is not available up to now.

Because the measured quantity is local, it can give information about the presence and the extent of a QGP in rapidity space. One expects to observe the lowest value of the charge transfer fluctuations at midrapidity, where the energy density is the highest and where the plasma is located. The charge correlation length and therefore the local charge fluctuations are expected to be much lower in a quark-gluon plasma than in a hadron gas.

Fig. 3 (Left) shows the charge transfer fluctuations $D_u/(dN_{ch}/d\eta)$ excitation function calculated from our sample of central Pb+Pb/Au+Au qMD events. $D_u/(dN_{ch}/d\eta)$ is compatible with the HIJING and hadron-string transport model UrQMD result calculated in [21, 22] at $\sqrt{s_{NN}} =$ 200 GeV. $D_u/(dN_{ch}/d\eta)$ is stable down to the SPS energy range and then decreases with beam energy when reaching the baryon-rich sector at lower AGS energies. The result is thus clearly in-

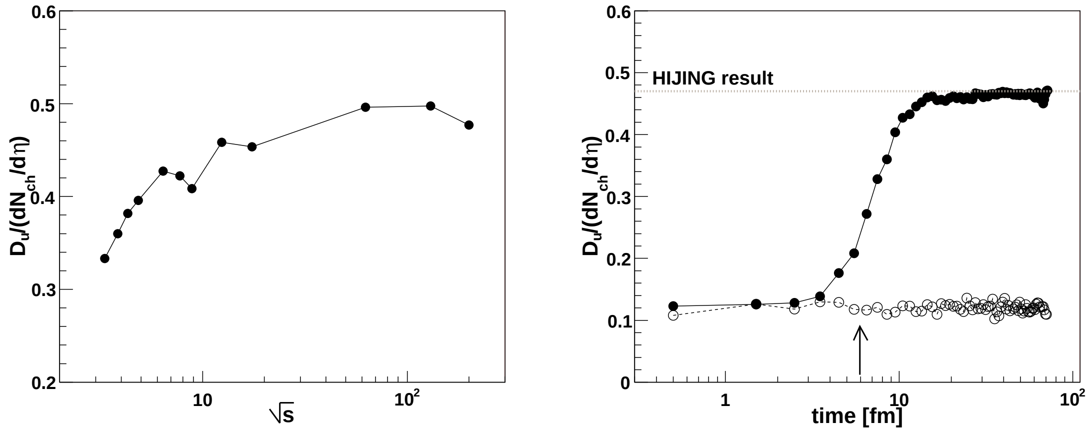

Figure 3:
Left : Charge transfer fluctuations $D_u/(dN_{ch}/d\eta)$ calculated with a set of central Au+Au/Pb+Pb qMD events as a function of $\sqrt{s}$. The total acceptance corresponds to STAR capabilities with $y = \pm 1$.
Right : Charge transfer fluctuations at midrapidity ($\Delta y = \pm 1$) and separation at $\eta = 0$ as a function of time within the qMD model for Au+Au reactions at $\sqrt{s_{NN}} = 200$ GeV. Full symbols are the result of full qMD simulations. Open symbols result from calculations where the procedure mapping colour neutral clusters of quarks to hadrons is not performed. The arrow depicts the hadronization time.

compatible with the QGP result at $\sqrt{s_{NN}} = 200$ GeV even though the qMD quark system was well into the QGP phase during the first 6 fm/c.

The results from the present calculations as a function of time are shown in Fig. 3 (Right) for central Au+Au events at $\sqrt{s_{NN}} = 200$ GeV. As expected, the correlation length (at central rapidities) is small, with $D_u/(dN_{ch}/d\eta) \approx 0.1$, as long as the system is in the quark phase. However, similar to the charge ratio fluctuations discussed above, the charge transfer measure increases with time up to its hadronic value of $D_u/(dN_{ch}/d\eta) \approx 0.5$ when hadronization has occurred. The final state result is in agreement with the value given by HIJING calculations and therefore is in line with the hadronic expectation [20, 21, 22, 23]. Also, similarly to charge transfer fluctuations, $D_u/(dN_{ch}/d\eta) \approx 0.1$ during the whole evolution when the procedure mapping clusters of quarks into hadrons is not applied. qMD estimates for charge transfer fluctuations are consistent with the model studied in [60], also including a partonic/hadronic transition.

We finally turn to the analyse of the baryon-strangeness correlation coefficient C_{BS}. It was argued in [25] that the correlation between baryon number and strangeness strongly differs whether the system is in a QGP or in a hadronic phase. In a QGP, strange quarks will always carry baryon number $\pm\frac{1}{3}$ which strongly correlates baryon number and strangeness. The situation is different in a hadron gas where strangeness can be carried without baryon number, e.g. with kaons. Following [25], we calculate the C_{BS} correlation coefficient on an event-by-event basis :

$$C_{BS} = -3\frac{\langle BS\rangle - \langle B\rangle\langle S\rangle}{\langle S^2\rangle - \langle S\rangle^2} = -3\frac{\chi_{BS}}{\chi_S} \tag{3.4}$$

Where B and S stand for the baryon number and total strangeness respectively in the studied rapidity

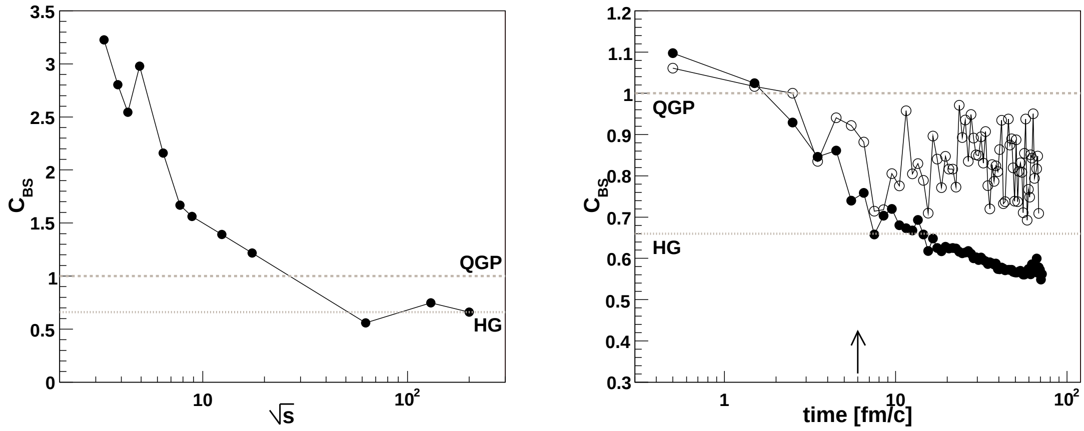

Figure 4:
Left :Correlation coefficient C_{BS} for central Au+Au/Pb+Pb qMD events as a function of $\sqrt{s_{NN}}$. The rapidity window used is $y_{\max} = 0.5$.
Right : C_{BS} correlation coefficient as a function of time for central Au+Au reactions at $\sqrt{s_{NN}} = 200$ GeV. Full circles are the result of a default qMD calculation and open circles the result of qMD without the mapping procedure applied. Also shown are the predicted values for a hadron gas and a QGP. The arrow depicts the hadronization time.

slice. The expectation value in an ideal QGP is $C_{BS} = 1$ and $C_{BS} = 0.66$ in a resonance gas at temperature $T = 170$ MeV and chemical potential $\mu = 0$ corresponding to conditions obtained at RHIC.

The energy scan of C_{BS} for central Au+Au/Pb+Pb collisions as calculated with final state qMD is shown as full circles in Figure 4 (Left). As discussed in [25], C_{BS} increases with an increase of the baryon chemical potential μ_B, i.e. when going to lower beam energies. With increasing collision energy, and therefore decreasing μ_B, C_{BS} goes down to $C_{BS} \approx 0.6$ at the highest RHIC energy available, compatible with the value for a fully thermalized hadron gas.

The behaviour of C_{BS} as a function of time for the dynamical recombination model under study is depicted in Fig. 4 (Right) in full symbols with the mapping procedure applied and in open symbols when not. For early times, C_{BS} starts from the expected value of unity in agreement with the ideal weakly coupled quark-gluon plasma value. With the recombination of the quarks, C_{BS} approaches the hadron-gas value $C_{BS} \approx 0.6$ when the hadronization procedure is applied (Full symbols). Similarly to charge ratio fluctuations and charge transfer fluctuations, C_{BS} is flat within uncertainties around the partonic expectation value when the hadronization procedure is not applied (open symbols).

4. Conclusion

We have studied charge ratio fluctuations $\tilde{D}$, charge transfer fluctuations $D_u/(dN/d\eta)$ and the baryon strangeness correlation coefficient C_{BS} within the quark Molecular Dynamics, qMD model, including an explicit transition from partonic to hadronic matter. The hadronization mechanism implemented in qMD consists of the dynamical recombination of coloured quarks into hadrons in an expanding medium.

For the above discussed probes of the QGP, (all based on the correlations and fluctuations of conserved charges), we find that the final state result is not compatible with a QGP scenario in the whole energy range scanned even at the highest energies where the system, in the present model, is in the quark phase for a few fm/c.

At the highest RHIC energy ($\sqrt{s_{NN}} = 200$ GeV) where the system stays in the deconfined phase for 6 fm/c for central Au+Au collisions simulated with qMD, all studied quantities start from their QGP expectation values but reach the hadronic result in the final state. The loss of the signal is traced back to the recombination-hadronization procedure implemented in our model. Thus, the present investigation indicates clearly that the effect of hadronization can have a drastic influence on possibly all observable quantities of the QGP, based on the fractional charges of the quarks and the fluctuations of conserved charges.

Acknowledgments

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References

[1] M. Gazdzicki and S. Mrowczynski, Z. Phys. C **54**, 127 (1992).

[2] S. Mrowczynski, Phys. Lett. B **430**, 9 (1998) [arXiv:nucl-th/9712030].

[3] M. Bleicher *et al.*, Nucl. Phys. A **638**, 391 (1998).

[4] M. Bleicher *et al.*, Phys. Lett. B **435**, 9 (1998) [arXiv:hep-ph/9803345].

[5] M. A. Stephanov, K. Rajagopal and E. V. Shuryak, Phys. Rev. Lett. **81**, 4816 (1998) [arXiv:hep-ph/9806219].

[6] S. Jeon and V. Koch, Phys. Rev. Lett. **83**, 5435 (1999) [arXiv:nucl-th/9906074].

[7] M. A. Stephanov, K. Rajagopal and E. V. Shuryak, Phys. Rev. D **60**, 114028 (1999) [arXiv:hep-ph/9903292].

[8] S. Mrowczynski, Phys. Lett. B **459**, 13 (1999) [arXiv:nucl-th/9901078].

[9] A. Capella, E. G. Ferreiro and A. B. Kaidalov, Eur. Phys. J. C **11**, 163 (1999) [arXiv:hep-ph/9903338].

[10] S. Mrowczynski, Phys. Lett. B **465**, 8 (1999) [arXiv:nucl-th/9905021].

[11] M. Bleicher, J. Randrup, R. Snellings and X. N. Wang, Phys. Rev. C **62**, 041901 (2000) [arXiv:nucl-th/0006047].

[12] M. Asakawa, U. W. Heinz and B. Muller, Phys. Rev. Lett. **85**, 2072 (2000) [arXiv:hep-ph/0003169].

[13] M. Bleicher, S. Jeon and V. Koch, Phys. Rev. C **62**, 061902 (2000) [arXiv:hep-ph/0006201].

[14] S. Jeon, V. Koch, K. Redlich and X. N. Wang, Nucl. Phys. A **697**, 546 (2002) [arXiv:nucl-th/0105035].

[15] B. H. Sa, X. Cai, A. Tai and D. M. Zhou, Phys. Rev. C **66**, 044902 (2002) [arXiv:nucl-th/0112038].

[16] V. Koch, M. Bleicher and S. Jeon, Nucl. Phys. A **698**, 261 (2002) [Nucl. Phys. A **702**, 291 (2002)] [arXiv:nucl-th/0103084].

[17] Y. Hatta and M. A. Stephanov, Phys. Rev. Lett. **91**, 102003 (2003) [Erratum-ibid. **91**, 129901 (2003)] [arXiv:hep-ph/0302002].

[18] E. G. Ferreiro, F. del Moral and C. Pajares, Phys. Rev. C **69**, 034901 (2004) [arXiv:hep-ph/0303137].

[19] S. Mrowczynski, M. Rybczynski and Z. Wlodarczyk, Phys. Rev. C **70**, 054906 (2004) [arXiv:nucl-th/0407012].

[20] S. Haussler, S. Scherer and M. Bleicher, AIP Conf. Proc. **892**, 372 (2007) [arXiv:nucl-th/0611002].

[21] S. Jeon, L. Shi and M. Bleicher, J. Phys. Conf. Ser. **27**, 194 (2005) [arXiv:nucl-th/0511066].

[22] S. Jeon, L. Shi and M. Bleicher, Phys. Rev. C **73**, 014905 (2006) [arXiv:nucl-th/0506025].

[23] L. j. Shi and S. Jeon, Phys. Rev. C **72**, 034904 (2005) [arXiv:hep-ph/0503085].

[24] A. Majumder, V. Koch and J. Randrup, J. Phys. Conf. Ser. **27**, 184 (2005) [arXiv:nucl-th/0510037].

[25] V. Koch, A. Majumder and J. Randrup, Phys. Rev. Lett. **95**, 182301 (2005) [arXiv:nucl-th/0505052].

[26] V. P. Konchakovski, S. Haussler, M. I. Gorenstein, E. L. Bratkovskaya, M. Bleicher and H. Stoecker, Phys. Rev. C **73**, 034902 (2006) [arXiv:nucl-th/0511083].

[27] L. Cunqueiro, E. G. Ferreiro, F. del Moral and C. Pajares, Phys. Rev. C **72**, 024907 (2005) [arXiv:hep-ph/0505197].

[28] G. Torrieri, S. Jeon and J. Rafelski, Phys. Rev. C **74**, 024901 (2006) [arXiv:nucl-th/0503026].

[29] N. Armesto, L. McLerran and C. Pajares, Nucl. Phys. A **781**, 201 (2007) [arXiv:hep-ph/0607345].

[30] S. Jeon and V. Koch, Phys. Rev. Lett. **85**, 2076 (2000) [arXiv:hep-ph/0003168].

[31] S. Jeon and S. Pratt, Phys. Rev. C **65**, 044902 (2002) [arXiv:hep-ph/0110043].

[32] Q. H. Zhang, V. Topor Pop, S. Jeon and C. Gale, Phys. Rev. C **66**, 014909 (2002) [arXiv:hep-ph/0202057].

[33] C. Pruneau, S. Gavin and S. Voloshin, Phys. Rev. C **66**, 044904 (2002) [arXiv:nucl-ex/0204011].

[34] S. Haussler, H. Stoecker and M. Bleicher, Phys. Rev. C **73**, 021901 (2006) [arXiv:hep-ph/0507189].

[35] T. S. Biro, P. Levai and J. Zimanyi, Phys. Lett. B **347**, 6 (1995).

[36] J. Zimanyi, T. S. Biro, T. Csorgo and P. Levai, Phys. Lett. B **472**, 243 (2000) [arXiv:hep-ph/9904501].

[37] D. Molnar and S. A. Voloshin, Phys. Rev. Lett. **91**, 092301 (2003) [arXiv:nucl-th/0302014].

[38] R. C. Hwa and C. B. Yang, Phys. Rev. C **70**, 024904 (2004) [arXiv:hep-ph/0312271].

[39] R. J. Fries, B. Muller, C. Nonaka and S. A. Bass, Phys. Rev. Lett. **90**, 202303 (2003) [arXiv:nucl-th/0301087].

[40] R. J. Fries, B. Muller, C. Nonaka and S. A. Bass, Phys. Rev. C **68**, 044902 (2003) [arXiv:nucl-th/0306027].

[41] V. Greco, C. M. Ko and P. Levai, Phys. Rev. Lett. **90**, 202302 (2003) [arXiv:nucl-th/0301093].

[42] J. Adams *et al.* [STAR Collaboration], Phys. Rev. Lett. **92**, 052302 (2004) [arXiv:nucl-ex/0306007].

[43] R. C. Hwa and C. B. Yang, Phys. Rev. C **70**, 024905 (2004) [arXiv:nucl-th/0401001].

[44] M. Hofmann, J. M. Eisenberg, S. Scherer, M. Bleicher, L. Neise, H. Stoecker and W. Greiner, arXiv:nucl-th/9908031.

[45] S. Scherer and H. Stoecker, arXiv:nucl-th/0502069.

[46] S. Scherer, M. Hofmann, M. Bleicher, L. Neise, H. Stoecker and W. Greiner, New J. Phys. **3**, 8 (2001) [arXiv:nucl-th/0106036].

[47] M. Hofmann, M. Bleicher, S. Scherer, L. Neise, H. Stoecker and W. Greiner, Phys. Lett. B **478**, 161 (2000) [arXiv:nucl-th/9908030].

[48] S. Haussler, S. Scherer and M. Bleicher, arXiv:hep-ph/0702188.

[49] C. Nonaka, B. Muller, S. A. Bass and M. Asakawa, Phys. Rev. C **71**, 051901 (2005) [arXiv:nucl-th/0501028].

[50] A. Bialas, Phys. Lett. B **532**, 249 (2002) [arXiv:hep-ph/0203047].

[51] F. Jin, X.Z. Cai, H.Z. Huang, G.L. Ma and S. Zhang SQM 2007

[52] M. Bleicher *et al.*, J. Phys. G **25**, 1859 (1999) [arXiv:hep-ph/9909407].

[53] S. A. Bass *et al.*, Prog. Part. Nucl. Phys. **41**, 255 (1998) [Prog. Part. Nucl. Phys. **41**, 225 (1998)] [arXiv:nucl-th/9803035].

[54] C. A. Pruneau [STAR Collaboration], Heavy Ion Phys. **21**, 261 (2004) [arXiv:nucl-ex/0304021].

[55] G. D. Westfall [STAR collaboration], J. Phys. G **30**, S1389 (2004) [arXiv:nucl-ex/0404004].

[56] K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **89**, 082301 (2002) [arXiv:nucl-ex/0203014].

[57] J. Nystrand [PHENIX Collaboration], Nucl. Phys. A **715**, 603 (2003) [arXiv:nucl-ex/0209019].

[58] H. Sako and H. Appelshaeuser [CERES/NA45 Collaboration], J. Phys. G **30**, S1371 (2004) [arXiv:nucl-ex/0403037].

[59] C. Alt *et al.* [NA49 Collaboration], Phys. Rev. C **70**, 064903 (2004) [arXiv:nucl-ex/0406013].

[60] J. Zhou and C. Chen, Phys. Rev. ST Accel. Beams **9**, 104201 (2006).