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Possible resolutions of the *D*-puzzle

C. Nonaka,[1] B. Müller,[1] S. A. Bass,[1,2] and M. Asakawa[3]
[1]*Department of Physics, Duke University, Durham, North Carolina 27708*
[2]*RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973*
[3]*Department of Physics, Osaka University, Toyonaka 560-0043, Japan*

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We explore possible ways of explaining the net charge event-by-event fluctuations in Au+Au collisions observed in experiments at the Relativistic Heavy Ion Collider within a quark recombination model. We estimate the number of quarks at recombination and their implications for the predicted net charge fluctuations. We also discuss the consequences of diquark and quark-antiquark clustering above the deconfinement temperature.

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Fluctuations of the net electric charge of all particles emitted into a specified rapidity window have been proposed as a possible signal for the formation of deconfined quark matter in relativistic heavy ion collisions [1,2]. The argument at the basis of this proposal is that charge fluctuations in a quark-gluon plasma are expected to be significantly smaller (by a factor 3–4) than in a hadronic gas. Because the net charge contained in a given volume is locally conserved and can be changed only by particle diffusion, thermal fluctuations generated within the deconfined phase could survive hadronization and final-state interactions. Quantitative estimates of the diffusion of net charge showed that the survival of these fluctuations from an early stage of the collision requires a moderately large rapidity window [3].

The most widely used measure for the entropy normalized net charge fluctuations is the D measure [2]:

$$D = 4\langle(\Delta Q)^2\rangle / N_{\rm ch}, \tag{1}$$

where $\langle(\Delta Q)^2\rangle$ denotes the event-by-event net charge fluctuation within a given rapidity window Δy and $N_{\rm ch}$ is the total number of charged particles emitted in this window. For a free plasma of quarks and gluons $D \approx 1$, whereas for a free pion gas $D \approx 4$. For the comparison with experimental data a number of corrections for acceptance and global charge conservation must be applied to the expression for D [4]. The relation of the D measure to other measures of net charge fluctuations has been discussed by various authors [5–7].

Several experiments have measured net charge fluctuations in heavy ion collisions at the CERN Super-Proton Synchrotron (SPS) and at the Relativistic Heavy Ion Collider (RHIC) in Brookhaven [8–11]. The results for D are generally somewhat smaller than 4 but much larger than the value predicted for a free quark-gluon gas. For example, the STAR collaboration has measured $D = 2.8 \pm 0.05$ in central Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV [8], before applying corrections for global charge conservation and other effects [4]. The PHENIX experiment measured net charge fluctuations in a limited azimuthal acceptance window around midrapidity, which extrapolate to a value $D \approx 3$ [9]. These results are surprising, because many other observables indicate that a deconfined quark-gluon plasma is formed in these collisions.

Białas has argued that the measured values of D could be compatible with the net charge fluctuations in a deconfined quark phase, if hadronization proceeds according to simple valence quark counting rules [12] and if gluons do not play an active role in the hadronization. Indeed, hadron abundances measured in relativistic heavy ion collisions at the SPS and RHIC are well described by combinatorial quark recombination models, such as ALCOR [13]. We here pursue this idea further and explore various scenarios of valence quark recombination to better understand how the puzzle posed by the measured value of D can be resolved. We also discuss the constraints on such a resolution from the measured final-state entropy and the second law of thermodynamics.

The recombination of thermalized valence quarks has recently been proposed as the dominant mechanism for the production of hadrons with transverse momenta of a few GeV/c in Au+Au collisions at RHIC [14–19]. The RHIC data have provided compelling evidence for this hadronization mechanism. Valence quark recombination explains the enhancement of baryon emission, compared with meson emission, in the range of intermediate transverse momenta (roughly from 2 to 5 GeV/c), and it naturally describes the observed hadron species dependence of the elliptic flow in the same momentum region in terms of a universal elliptic flow curve for the constituent quarks [14,17,18].

When one wants to describe hadronization by quark recombination not only at intermediate momenta, but over the entire hadron momentum range, except for very large momenta where parton fragmentation is thought to dominate, entropy becomes an important consideration. The naive application of recombination can easily entail a violation of the second law of thermodynamics, because the number of independent particles decreases when valence quarks recombine into hadrons. Greco *et al.* [15] have argued that this problem may be circumvented by including the decay of hadronic resonances, such as the ρ-meson, into the calculation of the entropy balance. We next discuss the entropy problem in a more comprehensive manner by considering the entropy content in realistic models of the hadronic phase (the resonance gas model) and the quark phase [lattice quantum chromodynamics (QCD) calculations].

The equilibrium entropy per particle is only a fixed constant (3.60 for bosons, 4.20 for fermions) for free massless

TABLE I. $m_{PS}/m_V = 0.65$ case. All calculations are performed with $N_t = 6$. Statistical errors are shown only for s/s_{SB}.

T/T_c	ε/T^4	P/T^4	$\varepsilon/\varepsilon_{SB}$	P/P_{SB}	s/s_{SB}
0.92	8.03	0.88	0.489	0.172	0.413 ± 0.051
1.04	11.91	1.28	0.725	0.250	0.612 ± 0.043
1.30	13.67	2.75	0.833	0.536	0.762 ± 0.038
1.61	14.44	3.35	0.879	0.653	0.826 ± 0.038
2.00	12.93	3.96	0.787	0.772	0.784 ± 0.038

TABLE II. Same as Table I except $m_{PS}/m_V = 0.80$.

T/T_c	ε/T^4	P/T^4	$\varepsilon/\varepsilon_{SB}$	P/P_{SB}	s/s_{SB}
0.80	3.73	0.17	0.227	0.033	0.181 ± 0.054
0.89	1.91	0.26	0.116	0.061	0.101 ± 0.041
1.12	12.08	1.62	0.736	0.316	0.636 ± 0.044
1.38	11.98	2.66	0.730	0.519	0.679 ± 0.042
1.67	11.80	3.54	0.719	0.690	0.712 ± 0.039

particles. For particle with mass, the entropy per particle is a function of the particle mass m and the temperature T. For $m/T > 3$ a good approximation is $S/N = 3.50 + m/T$. The inclusion of mass is important, because a large fraction of the hadrons created at the moment of hadronization is quite heavy—the average hadron mass at chemical freezeout is about 800 MeV/c^2 in the absence of medium induced modifications of the hadron masses [20,21]. The average value of the entropy per hadron therefore significantly exceeds the canonical value $(S/N)_0 \approx 4$. Including all known meson and baryon resonances, one obtains $\langle S/N \rangle \approx 7.58$. This value has an uncertainty of about ± 0.4 depending on the precise value of the hadronization temperature T_c, the precise number of resonances included, and how one treats the resonance widths.

An estimate of the final-state entropy per unit rapidity produced in central $\sqrt{s_{NN}} = 130$ GeV Au+Au collisions has recently been derived from experimental data (hadron yields, spectra, and source radii) by Pal and Pratt: $dS/dy = 4450 \pm 400$ [22]. Using the measured charged multiplicity of $dN_{ch}/dy = 526 \pm 2(\text{stat}) \pm 36(\text{syst})$ [8], this value can be converted into an estimate of the final entropy per particle of $S/N \approx (dS/dy)/(1.5 dN_{ch}/dy) \approx 5.64 \pm 0.6$, which is much smaller than the equilibrium value for the full resonance gas at chemical freeze-out. This is not surprising, because most hadrons initially produced at T_c are short-lived and decay prior to the measurement of the final-state multiplicity.

At the same time, the entropy content of the quark phase is strongly reduced because of interactions near T_c. Recently, the CP-PACS collaboration [23] and the Bielefeld group [24] have calculated the pressure and energy density at finite temperature and zero chemical potential on the lattice. To extract physical quantities from lattice QCD calculations, extrapolations (to the thermodynamic limit, continuum limit, etc.) are mandatory. Because of a finer lattice spacing at a given temperature, the CP-PACS simulation for $N_t = 6$ is closer to the continuum limit and may be slightly better suited for the purpose of extracting the entropy density near T_c than the other calculations in Refs. [23,24]. However, we should keep in mind that all lattice data for thermodynamic quantities are still obtained with unphysically large quark masses.

We list the obtained values of ε/T^4, P/T^4, $\varepsilon/\varepsilon_{SB}$, P/P_{SB}, and s/s_{SB} at $m_{PS}/m_V = 0.65$ and 0.80 below in Tables I and II. ε, P, and s denote the energy density, pressure, and entropy density, respectively, and ε_{SB}, P_{SB}, and s_{SB}, are their values for the free gas of massless quarks and gluons on the lattice used in the simulation. The statistical errors are shown only for s/s_{SB}. Obviously, the size of the systematic errors are still substantial. However, at the same time, it is obvious that the entropy density of the quark-gluon plasma is considerably suppressed with respect to the corresponding Stefan-Boltzmann (SB) value near T_c.

On the basis of these results we conclude that:

(1) The entropy per particle in the hadronic gas, and therefore the entropy content of the hadronic phase at chemical freeze-out, is considerably larger than often assumed.

(2) The entropy density of the quark phase is significantly suppressed near T_c, most likely because of correlations among the quasiparticles caused by their strong interactions.

These two conclusions make the recombination picture of hadronization more compatible with the entropy constraint. If the quark-gluon plasma at hadronization consists of strongly interacting quasiparticles (e.g., constituent quarks) with strong correlations, and if many of the hadrons created at hadronization are heavy, quark recombination and the concomitant particle number decrease could be reconciled with the second law of thermodynamics.

At present, however, we cannot directly compare the entropy content of both phases, because the volume at hadronization is not unambiguously known. Besides, lattice calculations do not tell us the number of (quasi-)particles, because there is no lattice definition of particle density. Therefore, a more detailed comparison of the entropy content of the hadronic phase and the quark phase at hadronization remains as a problem for future investigations. However, the second law of thermodynamics gives us a rough estimate of the maximum hadronization time τ_c/c. The entropy density in the quark phase is given by the following:

$$
\begin{aligned}
s_Q &= \left.\frac{s_Q}{s_{SB}}\right|_{T/T_c=1.04} \times s_{SB}\, T^3 \\
&= 0.612 \times 21.53\, T^3, \qquad (2)
\end{aligned}
$$

where the value of s_Q/s_{SB} is taken from Table I. At $T = T_c = 170$ MeV, the entropy density of the quark phase is $s_Q = 8.4$ fm^{-3}. Using the entropy estimate by Pal and Pratt, $dS_H/dy = 4450$, the volume per unit rapidity of the hadron phase is $dV_H/dy = (dS_H/dy)/s_Q = 528$ fm^3. In the quark phase the volume per unit rapidity is given by $dV_Q/dy = \pi R^2 \tau_c$, assuming a boost-invariant longitudinal expansion, where $R \approx 7$ fm is the transverse radius in Au+Au collisions. From the second law of thermodynamics, $dV_Q/dy \leqslant dV_H/dy$, we obtain the maximum value of the hadronization time, $\tau_c = 3.4$ fm/c under the assumption of entropy conservation ($S_Q = S_H$) during hadronization. If there is an entropy difference between the hadronic phase and the quark phase because of viscous processes, heat conduction, and so on, or if hadronization occurs gradually, the system will have to hadronize earlier.

We now return to the calculation of net charge fluctuations in a bulk recombination scenario. The fluctuations of the net charge $Q = \sum_i q_i n_i$ are given by (the sum runs over quarks and antiquarks) the following:

$$\begin{aligned}\langle \delta Q^2 \rangle &\equiv \langle Q^2 \rangle - \langle Q \rangle^2 \\ &= \sum_i (q_i)^2 \langle n_i \rangle + \sum_{i,k} c_{ik}^{(2)} \langle n_i \rangle \langle n_k \rangle q_i q_k, \end{aligned} \tag{3}$$

where $c_{ik}^{(2)}$ are the normalized two-particle correlation functions as follows:

$$c_{ii}^{(2)} = \frac{\langle n_i(n_i-1)\rangle}{\langle n_i \rangle^2} - 1; \tag{4}$$

$$\begin{aligned} c_{ik}^{(2)} &= \frac{\langle n_i n_k \rangle}{\langle n_i \rangle \langle n_k \rangle} - 1 \\ &= \frac{\langle (n_i - \langle n_i \rangle)(n_k - \langle n_k \rangle)\rangle}{\langle n_i \rangle \langle n_k \rangle} \quad (i \neq k). \end{aligned} \tag{5}$$

The last expression in Eq. (5) shows that $c_{ik}^{(2)}$ is positive if there is a positive correlation between the quarks of flavors i and k. In the absence of two-particle correlations, Eq. (3) can be rewritten as follows:

$$\langle \delta Q^2 \rangle = \frac{4}{9}(N_u + N_{\bar{u}}) + \frac{1}{9}(N_d + N_{\bar{d}} + N_s + N_{\bar{s}}), \tag{6}$$

where $N_i = \langle n_i \rangle$ denotes the average number of constituent quarks of flavor i.

Our strategy is now as follows: Knowing the number of final-state charged hadrons within a given rapidity interval, dN_{ch}/dy, we can extrapolate by means of the statistical hadronization model [20,21] to the thermal abundances of hadrons produced at the critical temperature T_c. We can then determine the total number and flavor distribution of valence quarks contained in these hadrons. Assuming valence quark recombination, using Eq. (6), and neglecting correlations, we can then calculate the expected net charge fluctuation at hadronization. The prediction for $\langle \delta Q^2 \rangle$ derived in this way can then be compared with the measured value of this quantity.

We estimate the number of constituent quarks at the moment of recombination by starting from the value $dS/dy \approx 4450$ derived by Pal and Pratt. Assuming that entropy remains conserved during the expansion of the hadronic gas phase and using the calculated value of the entropy per hadron ($S/N = 7.58$) for a resonance gas at T_c, we obtain an estimate for the number of hadrons at hadronization: $dN_{\mathrm{had}}/dy = 587 \pm 53$. These 587 hadrons contain a total of 1300 ± 120 quarks and antiquarks. Applying Eq. (6), this yields the following estimate for the net charge fluctuations from quark recombination:

$$d\langle \delta Q^2 \rangle_{\mathrm{q}}/dy = 331 \pm 27. \tag{7}$$

The measured value of the hadronic net charge fluctuation is as follows [8]:

$$\begin{aligned} d\langle \delta Q^2 \rangle_{\mathrm{had}}/dy &= \frac{1}{4} D \times dN_{\mathrm{ch}}/dy \\ &= \frac{1}{4} \times (2.8 \pm 0.05) \times (526 \pm 2 \pm 36) \\ &= 368 \pm 33\,. \end{aligned} \tag{8}$$

We note that the errors in Eqs. (7) and (8) are correlated because they derive, in large part, from the same uncertainty in the measured value of the charged particle multiplicity.

Considering the systematic uncertainties inherent in the estimate (7), we conclude that the observed magnitude of the net charge fluctuations in Au+Au collisions at RHIC is compatible with the mechanism of bulk hadronization via recombination of valence quarks in the absence of significant net charge correlations among the quarks. One could turn the argument around and ask which value of S/N at T_c, combined with the Pal-Pratt estimate of the final entropy, would reproduce the measured charge fluctuations. The answer is $S/N = 6.82$. Including the theoretical uncertainty of S/N and the experimental error in dN_{ch}/dy, this is within one standard deviation from the best value. Clearly, a more detailed estimate of the possible production of entropy in the hadronic phase would be desirable to better constrain the analysis. Another source of uncertainty in our analysis is the possibility that the net-charge fluctuations increase modestly during the hadronic phase owing to diffusion [3].

Because the difference between the value (7) obtained by quark recombination and the measured value [Eq. (8)] may survive improvements in theory and experiment, it makes sense to discuss a modified variant of the recombination process. Recently, quenched lattice QCD calculations have shown evidence for the existence of mesonic bound state correlations even above the critical temperature [25–28]. Brown *et al.* argued within an effective field theory that bound states of charmed quark mesons, light quark mesons, and gluons exist above T_c [29]. These findings suggest that qq and $q\bar{q}$ pairs may participate in hadronization mechanism as "elementary" constituents, just like individual quarks and antiquarks. To explore such a scenario, we modified Eq. (3) as follows:

$$\begin{aligned} \langle \delta Q^2 \rangle &= \sum_i (q_i)^2 (N_i + N_{\bar{i}}) \\ &\quad + \sum_{ij} (q_i + q_j)^2 \langle n_{ij} \rangle + \sum_{ij} (q_i - q_j)^2 \langle \bar{n}_{ij} \rangle, \end{aligned} \tag{9}$$

where n_{ij} and $\bar{n}_{ij}$ are the number of qq and $\bar{q}\bar{q}$ pairs (diquarks) and $q\bar{q}$ pairs, respectively. For simplicity, we assume that the average number of diquarks and $q\bar{q}$ pairs is proportional to the products of the individual quark numbers: $\langle n_{ij} \rangle = \alpha(N_i N_j + N_{\bar{i}} N_{\bar{j}})$; $\langle \bar{n}_{ij} \rangle = \beta N_i N_{\bar{j}}$, where α and β are the relative pairing weights. We have again neglected the correlation terms.

The first term in Eq. (9) yields Eq. (6). The second term, which denotes the contribution from diquarks, is given by the following:

$$\begin{aligned} &\sum_{ij} (q_i + q_j)^2 \langle n_{ij} \rangle \\ &\quad = \frac{16}{9} \alpha N_u N_u + \frac{4}{9} \alpha (N_d N_d + N_s N_s + N_d N_s) \\ &\qquad + \frac{1}{9} \alpha (N_u N_d + N_u N_s) + (q \to \bar{q}), \end{aligned} \tag{10}$$

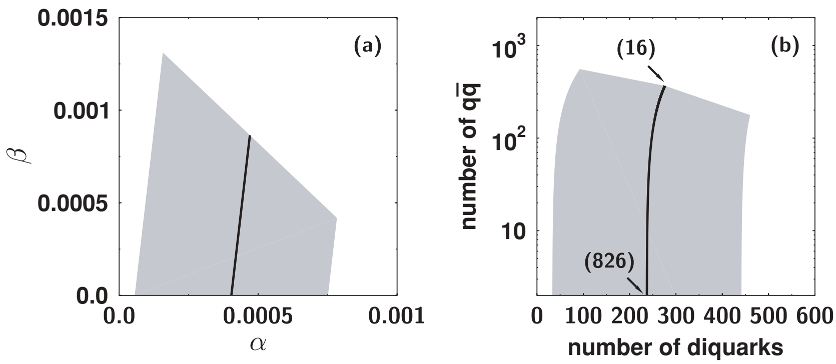

FIG. 1. (a) Relation between the weight of the contributions from diquarks and $q\bar{q}$ pairs in the recombination process. The solid line corresponds to a fixed total number of quarks and antiquarks of 1302. The gray band represents the systematic uncertainty stemming from the measured value of the charged particle multiplicity. (b) Relation between the sum of individual quarks and antiquarks that contribute to the first term of Eq. (9) (n_q, in parenthesis) and the number of diquarks or $q\bar{q}$ pairs participating in the recombination process.

whereas the third term, denoting the contribution from quark-antiquark pairs, is as follows:

$$\sum_{ij}(q_i - q_j)^2\langle\bar{n}_{ij}\rangle = \beta\,(N_d N_{\bar{u}} + N_s N_{\bar{u}} + N_u N_{\bar{d}} + N_u N_{\bar{s}}). \qquad (11)$$

We can now constrain the parameters α and β using the experimental value of $\langle\delta Q^2\rangle$. The total number of quarks and antiquarks on the right-hand side of Eq. (9) is constrained to be the same as that obtained from the statistical model.

Figure 1(a) shows the relation between the weights of qq and $q\bar{q}$ pairs. This calculation is done in the simplest case ($N_u = N_{\bar{u}} = N_d = N_{\bar{d}}$, $N_s = N_{\bar{s}}$). The important point is the existence of the region where both α and β are positive, which confirms the possibility of a contribution from diquarks and $q\bar{q}$ pairs in the hadronization mechanism. Diquark pairs are more favored than $q\bar{q}$ pairs in the sense that a solution with $\beta = 0$ is possible, but one with $\alpha = 0$ is not. In fact, the value of β is not well constrained by the charge fluctuations, because of the difference between the charge of qq and $q\bar{q}$ in Eqs. (10) and (11). For example, in the simplest case, $\sum_{ij}(q_i + q_j)^2\langle n_{ij}\rangle \sim \frac{42}{9}\alpha N_u^2$ and $\sum_{ij}(q_i - q_j)^2\langle\bar{n}_{ij}\rangle \sim 2\beta N_u^2$, which implies that diquarks are favored by a factor of about 2. Perturbative QCD suggests that the $q\bar{q}$ channel is more attractive than the qq channel, implying $\alpha < \beta$ in Eq. (9). However, because the lattice results indicate that hadronization occurs via strong interactions between plasma quasiparticles, it is not clear that this perturbative argument is applicable.

To clarify the relative numbers of diquarks, quark-antiquark pairs, and individual (anti-)quarks participating in the recombination process, we plot the relation among $\sum_i(N_i + N_{\bar{i}})$ for quarks and antiquarks, $\sum_{ij}\langle n_{ij}\rangle$ for diquarks, and $\sum_{ij}\langle\bar{n}_{ij}\rangle$ for quark-antiquark pairs in Fig. 1(b). For example on the horizontal axis of Fig. 1(b), we have $\sum_i(N_i + N_{\bar{i}}) = 826$, $\sum_{ij}\langle n_{ij}\rangle = 237$, and $\sum_{ij}\langle\bar{n}_{ij}\rangle = 1$, showing that diquark clustering dominates. The numbers of quarks and antiquarks decrease linearly as those of diquarks and quark-antiquark pairs increase along the solid line, respectively. However, in this case with a few quarks and antiquarks, hadrons are predominantly created from diquark or quark-antiquark clusters, which is difficult to reconcile with the elliptic flow data from RHIC [30,31], because that data strongly suggests a constituent quark counting rule [14,15,18].

In summary, we have investigated charged particle fluctuations at RHIC in the framework of the parton recombination model of hadronization and find that within the present systematic uncertainties parton recombination is compatible with the measured charged-particle fluctuations. We find that the behavior of the entropy density for an interacting deconfined system close to T_c and the entropy per particle for the massive resonance gas support the recombination picture. Finally, we have investigated the possibility of bound state correlations above T_c and find them consistent with the parton recombination approach as well, albeit constrained by the valence quark number scaling observed in the data.

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[1] M. Asakawa, U. Heinz, and B. Müller, Phys. Rev. Lett. **85**, 2072 (2000).
[2] S. Jeon and V. Koch, Phys. Rev. Lett. **85**, 2076 (2000).
[3] E. V. Shuryak and M. A. Stephanov, Phys. Rev. C **63**, 064903 (2001); M. Abdel-Aziz and S. Gavin, *ibid.*, **70**, 034905 (2004).
[4] M. Bleicher, S. Jeon, and V. Koch, Phys. Rev. C **62**, 061902(R) (2000).
[5] S. Mrówczyski, Phys. Rev. C **66**, 024904 (2002).
[6] J. Zaranek, Phys. Rev. C **66**, 024905 (2002).
[7] J. Nystrand, E. Stenlund, and H. Tydesjo, Phys. Rev. C **68**, 034902 (2003).
[8] J. Adams *et al.* (STAR Collaboration), Phys. Rev. C **68**, 044905 (2003); G. D. Westfall (STAR Collaboration), J. Phys. G. **30**, S1389 (2004).
[9] K. Adcox *et al.* (PHENIX Collaboration), Phys. Rev. Lett. **89**, 082301 (2002); J. Nystrand (PHENIX Collaboration), Nucl. Phys. **A715**, 603 (2003).
[10] H. Sako and H. Appelshäuser (CERES/NA45 Collaboration), J. Phys. G **30**, S1371 (2004).

[11] C. Alt *et al.* (NA49 Collaboration), Phys. Rev. C **70**, 064903 (2004).
[12] A. Białas, Phys. Lett. **B532**, 249 (2002).
[13] T. S. Biró, P. Lévai, and J. Zimányi, Phys. Lett. **B347**, 6 (1995); J. Zimányi, P. Lévai, and T. S. Biró, Heavy Ion Phys. **17**, 205 (2003).
[14] R. J. Fries, B. Müller, C. Nonaka, and S. A. Bass, Phys. Rev. Lett. **90**, 202303 (2003); Phys. Rev. C **68**, 044902 (2003).
[15] V. Greco, C. M. Ko, and P. Lévai, Phys. Rev. Lett. **90**, 202302 (2003); Phys. Rev. C **68**, 034904 (2003).
[16] R. C. Hwa and C. B. Yang, Phys. Rev. C **67**, 034902 (2003); Phys. Rev. C **67**, 064902 (2003).
[17] S. A. Voloshin, Nucl. Phys. **A715**, 379 (2003).
[18] D. Molnár and S. A. Voloshin, Phys. Rev. Lett. **91**, 092301 (2003).
[19] P. F. Kolb, L. W. Chen, V. Greco, and C. M. Ko, Phys. Rev. C **69**, 051901(R) (2004).
[20] T. Renk, Phys. Rev. C **68**, 064901 (2003).
[21] P. Braun-Munzinger, D. Magestro, K. Redlich, and J. Stachel, Phys. Lett. **B518**, 41 (2001); F. Becattini and U. W. Heinz, Z. Phys. C **76**, 269 (1997) [Erratum-*ibid.* C **76**, 578 (1997)]; J. Cleymans and K. Redlich, Phys. Rev. C **60**, 054908 (1999); J. Rafelski and J. Letessier, Phys. Rev. Lett. **85**, 4695 (2000).
[22] S. Pal and S. Pratt, Phys. Lett. **B578**, 310 (2004).
[23] A. Ali Khan *et al.* (CP-PACS Collaboration), Phys. Rev. D **64**, 074510 (2001).
[24] F. Karsch, E. Laermann, and A. Peikert, Phys. Lett. **B478**, 447 (2000).
[25] M. Asakawa and T. Hatsuda, Phys. Rev. Lett. **92**, 012001 (2004).
[26] F. Karsch, E. Laermann, P. Petreczky, S. Stickan, and I. Wetzorke, Phys. Lett. **B530**, 152 (2002).
[27] S. Datta, F. Karsch, P. Petreczky, and I. Wetzorke, Phys. Rev. D **69**, 094507 (2004).
[28] H. Matsufuru, T. Umeda, and K. Nomura, [arXiv:hep-lat/0401010].
[29] G. E. Brown, C.-H. Lee, M. Rho, and E. Shuryak, J. Phys. G **30**, S1275 (2004).
[30] S. S. Adler *et al.* (PHENIX Collaboration), Phys. Rev. Lett. **91**, 182301 (2003).
[31] J. Adams *et al.* (STAR Collaboration), Phys. Rev. Lett. **92**, 052302 (2004).