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Radiative parton energy loss and baryon stopping in AA collisions

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The baryon stopping in hadron and nucleus collisions has attracted much attention for a long time. However, presently, there is no answer to the most basic question about the processes with baryons: whether the baryon number carriers are quarks. In [1] it was proposed that in the topological expansion (TE) scheme [2, 3] a purely gluonic object – the so-called string junction (SJ) may play role of the baryon number carrier. In this picture the baryon number transfer is associated with the transfer of the SJ.

In the standard quark-gluon string model (QGSM) [4–6], based on the TE scheme [2], the baryon is treated as a quark-diquark system with a point like diquark in the $\{\bar{3}\}$ color state. It means that the SJ belongs to diquark, and diquarks/antidiquarks are playing the role of the baryon number carriers in processes with baryons (we denote this mechanism by D-SJ). For the D-SJ mechanism the net proton ($\Delta p = p - \bar{p}$) midrapidity density in pp collisions is related to the diquark distribution in the proton at small fractional momentum x, where it is $\propto x^{\alpha_R(0)-2\alpha_N(0)}$ with $\alpha_R(0) \approx 0.5$ and $\alpha_N(0) \approx -0.5$ intercepts of the meson and nucleon Regge trajectories. This leads to the energy dependence of the net proton midrapidity density $dN_{\Delta p}/dy \propto 1/s^{2.25}$. This disagrees strongly with the experimentally observed at ISR energies s-dependence $dN_{\Delta p}/dy \propto 1/s^n$ with $n \approx 0.25$. The model with the diquarks in the antitriplet color state also underestimates the midrapidity net baryon production in AA collisions [7, 8]. In [9] it was proposed that the baryon number transfer over a large rapidity interval can be related to breaking of the antitriplet diquark due to its transition from $\{\bar{3}\}$ to $\{6\}$ color state after one gluon t-channel exchange. The transition $D_{\{\bar{3}\}} \to D_{\{6\}}$ should lead to creation of the string configuration with the SJ located near the valence quark (we denote this mechanism as q-SJ). Hadronization of such string configurations leads naturally to the energy dependence of the midrapidity net proton density $dN/dy \propto 1/s^{\alpha_R(0)/2}$ which agrees with the data. Contribution of the q-SJ mechanism of the baryon number transfer over a large rapidity interval should be enhanced in AA collisions due to increase of the probability of the $D_{\{\bar{3}\}} \to D_{\{6\}}$ transition in the nuclear matter. Similarly to pp collisions, in AA collisions the diquark breaking leads to the net proton midrapidity distribution $\propto 1/s^{\alpha_R(0)/2}$.

The contribution from the q-SJ mechanism to the net proton midrapidity density in AA collisions becomes of the order of that from the ordinary D-SJ mechanism at $\sqrt{s} \sim 20\,\mathrm{GeV}$. At energies $\sqrt{s} \sim 10\,\mathrm{GeV}$ contribution of the q-SJ mechanism is relatively small. One more effect of the nuclear matter that can increase the baryon number flow to midrapidity, which can potentially be important at $\sqrt{s} \lesssim 10\,\mathrm{GeV}$, is the diquark radiative energy loss. It is of great interest to understand how large the radiative contribution to the baryon stopping can be. The question on the radiative mechanism at $\sqrt{s} \lesssim 10\,\mathrm{GeV}$ is of great importance in connection with the future experiments at NICA and the beam energy scan (BES) program at RHIC aimed to search for the QCD critical point. One of the important signals of the critical point may be the non-monotonic variation of the moments of the net-baryon distribution in the central rapidity region [10]. However, in the event-by-event fluctuations of the net-baryon yield a considerable contribution may come from the initial state fluctuations. One can expect that, similarly to the situation with the baryon number fluctuations in the QGP and the hadron gas [11], for the D-SJ mechanism the variance for the net-baryon number should be bigger by a factor of ~ 3 than in the picture with the baryon number associated with quarks.

In the present paper we study the effect of the diquark radiative energy loss in the nuclear matter on the net proton rapidity distribution for the D-SJ mechanism within the light-cone path integral approach [12–14] to the induced gluon emission. We perform calculations for $\alpha_s = 0.5$, for the transport coefficient $\hat{q} = 0.01\,\mathrm{GeV}^3$, for two values of the gluon mass $m_g = 400$ and $750\,\mathrm{MeV}$. We treat the diquark as a point like particle. We confront the results of our calculations with and without

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the induced gluon emission of the net proton rapidity spectrum (in the center of mass frame) with the data from NA49 Collaboration for Pb+Pb collisions at $E = 40\,\mathrm{GeV}$ ($\sqrt{s} = 8.76\,\mathrm{GeV}$) [15]. Our results show that the radiative correction partly fills in the minimum at $y = 0$. It increases the spectrum at $y = 0$ by a factor of about 1.35 and 1.12 for $m_g = 400$ and 750 MeV, respectively. We also study effect of the possible baryon diffusion in the hot QCD matter produced after interaction of the colliding nuclei at the proper time $\tau_0 \approx 2R_A/\gamma$ (γ is the nucleus Lorentz factor in the center of mass frame). The change of the baryon rapidity is related to its random walk in the longitudinal z direction in the comoving frame of the QCD matter. For the diffusion mean squared rapidity fluctuations at $E = 40\,\mathrm{GeV}$ we obtain $\sigma_d \approx 0.3$. Calculations of the Gaussian smearing with this value of σ_d show that the diffusion partly fills in the minimum at $y = 0$ of the net proton rapidity spectrum. Although the diffusion effect is relatively weak, it may be important for the event-by-event net proton fluctuations for the rapidity window Δy about $\sim 2{-}3$ units of σ_d. In this regime the diffusion can modify somewhat the primordial net proton yield fluctuations. But, at the same time, it is clear that for $\Delta y/\sigma_d \sim 3$ this modification cannot be strong. For this reason the net baryon charge fluctuations cannot be described by the grand canonical ensemble formulas which require $\sigma_d \gg \Delta y$, and one cannot expect to observe a real critical regime. In the light of this, the absence of a clear signal of the critical point in the net proton fluctuations at $\sqrt{s} \sim 10\,\mathrm{GeV}$ for $|y| < 0.5$ in Au + Au collisions from STAR [16] is not surprising. For the diquark mechanism of the baryon flow, to a good accuracy, these fluctuations should be binomial. This agrees with the STAR observation [16] that the net proton fluctuations are close to binomial/Poissonian at $\sqrt{s} \sim 10\,\mathrm{GeV}$, where the antiproton yield becomes very small. In the scenario of [17], in which the carriers of baryon number are quarks, the binomial/Poissonian distribution occurs for the net quark fluctuations. In this case $\langle (N_{\Delta p} - \langle N_{\Delta p}\rangle)^2\rangle \approx \langle N_{\Delta p}\rangle/3$ (cf. [11]), which contradicts the STAR measurement [16]. Note that even without calculating the diffusion width σ_d, the existence of the dip in the experimental net proton distribution at $y = 0$ from NA49 [15] says that σ_d is considerably smaller than ~ 1. Because, numerical calculations show that for $\sigma_d \sim 1$ the diffusion should completely wash out the dip. So, one can say, that we have an experimental evidence that at $\sqrt{s} \sim 10$ GeV the net proton fluctuations for $\Delta y \sim 1$ cannot not be close the critical point regime.

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