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Jet quenching with T-dependent running coupling

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It is accepted that the strong suppression of the high-p_T particle spectra in AA collisions (usually called the jet quenching) observed at RHIC and LHC, is due to parton energy loss (radiative and collisional) in the quark-gluon plasma (QGP). The jet quenching is one of the major signals of the QGP formation in relativistic AA collisions. The main contribution to the parton energy loss comes from the radiative mechanism due to induced gluon emission [1–5]. The effect of the collisional energy loss turns out to be relatively weak [6, 7].

The available pQCD approaches to the radiative energy loss [1–5] are limited to the one gluon emission. The effect of multiple gluon radiation is usually accounted for in the approximation of independent gluon emission [8]. Altogether, the pQCD calculations within this approximation give a rather good agreement with the jet quenching data from RHIC and LHC (see e.g. [9] and references therein). However, it was found that, in the formulation with a unique temperature independent QCD coupling, the simultaneous description of the RHIC and LHC data requires to use somewhat smaller α_s at the LHC energies [9–12] (in [13, 14] a similar difference between jet quenching at RHIC and LHC energies has been found in terms of the transport coefficient $\hat{q}$). In [9–12] this fact has been demonstrated within the light-cone path integral (LCPI) approach to induced gluon emission [2], using the method developed in [15, 16], for running α_s which is frozen at low momenta at some value α_s^{fr}. There it was found that the RHIC data support a significantly larger value of α_s^{fr} than the LHC data. One of the reasons for this difference may be somewhat stronger thermal suppression of the effective QCD coupling in a hotter QGP at the LHC energies. To draw a firm conclusion on this possibility it is highly desirable to perform calculations with a temperature dependent α_s. And of course, it is clear that, even without respect to the problem with a joint description of the RHIC and LHC jet quenching data, an observation of the temperature dependence of α_s from the jet quenching data would be of great importance on its own. The case of the T-dependent coupling has not been discussed so far in the literature on jet quenching. In this work we perform such an analysis. We adapt the LCPI formalism to the case of the T-dependent running α_s, and perform a joint analysis of the jet quenching data on the nuclear modification factor R_{AA} from RHIC on 0.2 TeV Au + Au collisions obtained by PHENIX [17] for π^0-meson and from the LHC on 5.02 TeV Pb + Pb collisions obtained by ALICE [18], ATLAS [19], and CMS [20] for charged hadrons.

We consider the central rapidity region around $y = 0$. Our method for calculating the nuclear modification factor R_{AA} is similar to the one used in our previous jet quenching analyses [16, 12, 9]. For our basic version we use parametrization of running coupling $\alpha_s(Q,T)$ which has a short plateau α_s^{fr} around $Q_{fr} \sim \kappa T$, and then falls $\propto Q$ at small Q. This ansatz is motivated by the lattice calculation of the effective QCD coupling in the QGP [21] and the results obtained within the functional renormalization group [22]. We have determined the optimal values of the parameter κ fitting the data on the nuclear modification factor R_{AA} in 0.2 TeV Au + Au collisions at RHIC and in 5.02 TeV Pb + Pb collisions at the LHC. We have found that the RHIC data require somewhat smaller value of the parameter κ than the LHC data. But nevertheless the theoretical R_{AA} for 0.2 Au + Au collisions calculated with the optimal κ adjusted to fit the LHC data, is in reasonable agreement with the RHIC data ($\chi^2/d.p. \approx 0.7{-}0.8$). This differs drastically from the results for the T-independent α_s^{fr}, which leads to rather strong disagreement with the RHIC data ($\chi^2/d.p. \approx 4.4{-}4.8$) for the optimal value α_s^{fr} fitted to the LHC data. Thus, our analysis shows that the T-dependent α_s may largely eliminate the problem of different optimal QCD coupling for the RHIC and LHC energies. For parametrization with flat

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α_s at $Q < Q_{fr}$ with $Q_{fr} = \kappa T$ we obtained very similar results. We have checked that, in principle, for the T-dependent coupling by a relatively small increase of $\alpha_s(Q,T)$ at $Q \sim (1{-}3)\Lambda_{\rm QCD}$, as compared to the one-loop formula, for κ fitted to the LHC data one can significantly improve agreement with the RHIC data in the low p_T region. Such an increase of the $\alpha_s(Q,T)$ is not unrealistic, e.g., it may mimic an enhancement of the induced gluon emission at $T \sim T_c$ [23, 24] in the presence color-magnetic monopoles [25].

Our results may be viewed as the first direct evidence of the increase of the thermal suppression of α_s with rising QGP temperature.

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