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Jet quenching in mini-quark-gluon plasma: Medium modification factor I_{pA} for photon-tagged jets

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Heavy ion collision experiments at RHIC and the LHC led to the discovery of the Quark Gluon Plasma (QGP) formation in AA collisions. The most striking manifestations of the QGP formation in AA collisions are the strong suppression of high-p_T hadron spectra (jet quenching) and the transverse flow effects in the azimuthal correlations for soft hadrons. Jet quenching in AA collisions is due to radiative and collisional energy loss of fast partons in the hot QGP. The dominant contribution to the parton energy loss comes from the radiative mechanism due to induced gluon radiation [1, 2]. Hydrodynamic analyses of soft hadron production in AA collisions show that the QCD matter produced in AA collisions flows almost as a perfect fluid (for reviews, see, e.g., [3, 4]). In recent years, the azimuthal correlations in soft hadron production (the ridge effect), similar to that observed in AA collisions, have been observed in pp/pA collisions. The formation of a mini QGP (mQGP) fireball is the most popular explanation of the ridge/flow effects in pp/pA collisions (for a review, see [5]). There are several experimental evidences supporting the onset of the mQGP regime in pp/pA collisions at the charged hadron multiplicity density $dN_{ch}/d\eta \gtrsim 5$ [6, 7]. It is important that, from the point of view of the multiplicity density, conditions for the mQGP formation in pp/pA collisions are more favorable for events with jet production. Because in jet events the average multiplicity density of soft (underlying-event (UE)) hadrons is larger than the minimum-bias multiplicity by a factor of $\sim 2-2.5$ [8]. At the LHC energies in pp jet events we have $dN_{ch}^{ue}/d\eta \sim 10-15$ (and by a factor of $\sim 2-3$ larger values for pA collisions), that seems to be large enough to expect the mQGP formation (in the light of the results of [6, 7]). In the scenario with the mQGP formation in pp/pA collisions, the jet quenching effects must appear. Similarly to AA collisions, they should modify the jet fragmentation functions (FFs) and hadron spectra in pp/pA collisions as compared to predictions of the standard pQCD. The recent ALICE [9] measurement of the jet FF modification factor I_{pp} for the hadron-tagged jets in pp collisions at $\sqrt{s} = 5.02$ TeV seems to confirm the scenario with the mQGP formation and jet quenching in pp collisions, since the data [9] show a monotonic decrease of I_{pp} with the UE multiplicity expected for the scenario with the mQGP formation [10]. The results of [9] agree within errors with calculations of [11] in the framework of the light-cone path integral (LCPI) approach to induced gluon emission [2].

One of the promising ways to probe the jet quenching effects in pA collisions is measurement of the medium modification factor I_{pA} for the photon-tagged FFs for $\gamma +$ jet events. In analogy with the medium modification factor I_{AA} in AA collisions (see, e.g., [12, 13]), I_{pA}, for a given photon transverse momentum p_T^γ, is defined as the ratio

$$I_{pA}(z_T, p_T^\gamma) = D_h^{pA}(z_T, p_T^\gamma)/D_h^{pp}(z_T, p_T^\gamma), \qquad (1)$$

where $D_h^{pA,pp}$ are the photon-tagged FFs of the away-side hard partons to the associate charged hadron h for pA and pp collisions, $z_T = p_T^h/p_T^\gamma$, and p_T^h is the hadron transverse momentum. Experimentally, the photon-tagged FF D_h is the away-side associated hadron yield per trigger photon. In terms of the inclusive cross sections, D_h reads

$$D_h(z_T, p_T^\gamma) = \frac{p_T^\gamma d^3\sigma}{dp_T^h dp_T^\gamma dy^\gamma}\Big(\frac{d^2\sigma}{dp_T^\gamma dy^\gamma}\Big)^{-1}. \qquad (2)$$

The advantage of I_{pA} is that experimental D_h do not suffer from the uncertainties of the yield normalizations in pA/pp collisions (since both the numerator and the denominator in (2) are hard cross sections, and the normalization uncertainties are largely canceled in D_h). For the same reason, the theoretical I_{pA}, contrary to the nuclear modification factor R_{pA} for pA hadron spectra, is insensitive to uncertainties in the nuclear and proton PDFs.

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Recently, the midrapidity I_{pA} has been measured by the ALICE collaboration [14] for 5.02 TeV $p+\mathrm{Pb}$ collisions for the trigger photon momentum $12 < p_T^\gamma <$ < 40 GeV. The ALICE measurement gives $\langle I_{pA}\rangle \approx$ $0.84 \pm 0.11(\mathrm{stat}) \pm 0.19(\mathrm{sys})$. The z_T-dependence of I_{pA} obtained in [14] has some tendency of I_{pA} towards decrease with increasing z_T. This pattern, at least roughly, is what is expected in the scenario with the mQGP formation. Of course, to understand better whether the results of [14] are consistent with the scenario with the mQGP formation in pp/pA collisions, quantitative calculations of I_{pA} for this scenario are necessary. In this paper, we perform calculations of I_{pA} for conditions of the ALICE experiment [14]. We use the LCPI approach [2] to induced gluon emission with temperature dependent α_s [15], which has successfully been used in our recent analysis [16] of the available data on the nuclear modification factor R_{AA}.

We have calculated the medium modification factor I_{pA} for the photon-tagged jets in 5.02 TeV $p+\mathrm{Pb}$ collisions for the conditions of the ALICE experiment [14] in the scenario with the mQGP formation. Radiative and collisional energy losses of fast partons in the QGP have been evaluated with running $\alpha_s(Q,T)$ that has a plateau around $Q \sim \kappa T$. We perform calculations using $\kappa = 2.55$ fitted to the LHC heavy ion data on the nuclear modification factor R_{AA}. To understand the relative contribution to $dN_{ch}^{ue}(pA)/d\eta$ in pA jet events of hadrons that are not related to the mQGP fireball, we have performed simulation of the entropy deposition for pA jet events within the Monte Carlo wounded nucleon Glauber model in the form suggested in [17], which was successfully used in [18, 19] for description of a large amount of experimental data on AA and pA collisions from RHIC and the LHC. Our calculations show that jet quenching can lead to a deviation of I_{pA} from unity by $\sim 0.1{-}0.2$ for $z_T \sim 0.5{-}0.8$ for the scenario with the mQGP formation both in $p+\mathrm{Pb}$ and pp collisions. This, within errors, is consistent with the data from ALICE [14]. However, a definite conclusion about the presence or absence of jet quenching in pA collisions cannot be drawn due to large experimental errors of the ALICE data [14]. Our results demonstrate that this requires a significantly more accurate measurement of I_{pA} (with errors $\lesssim 0.1{-}0.2$).

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