Pis'ma v ZhETF, vol. 120, iss. 3, pp. 169 – 170

Jet quenching for hadron-tagged jets in pA collisions

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Submitted 29 June 2024
Resubmitted 29 June 2024
Accepted 1 July 2024

We calculate the medium modification factor I_{pA} for 5.02 TeV $p+\mathrm{Pb}$ collisions. We use the Monte-Carlo Glauber model to determine the parameters of the quark-gluon plasma fireball in pA jet events. Our calculations show that the jet quenching effect for I_{pA} turns out to be rather small. We have found that the theoretical I_{pA} as a function of the underlying event charged multiplicity density, within errors, agrees with data from ALICE [18] for 5.02 TeV $p+\mathrm{Pb}$ collisions. However, the experimental errors are too large to draw a firm conclusion on the possible presence of jet quenching.

DOI: 10.31857/S0370274X24080014, EDN: XFHYGF

The observation of the quark-gluon plasma (QGP) formation in AA collisions has sparked new interest in the idea of the QGP formation for small systems [1]. The analysis of [2] in the scenario of the strongly coupled QGP shows that even the smallest droplet of the QCD matter produced in pp/pA collisions can be described within hydrodynamics. In [3] it was argued that for pp/pA collisions the lower bound for applicability of hydrodynamical description is $dN_{ch}/d\eta \sim 3$. This is close to the estimate of [4].

Experimentally, the formation of a mini QGP in pp/pA collisions is supported by the observation of the ridge effect [5–8] in pp/pA collisions at the LHC energies and by the steep growth of the midrapidity strange particle production at charged multiplicity $dN_{ch}/d\eta \gtrsim 5$ [9]. The earlier analysis [10] of $\langle p_T \rangle$ as a function of multiplicity, employing van Hove's arguments [11], also supports the onset of QGP regime at such charged multiplicity density. There were suggested alternative non-hydrodynamical explanations of the ridge effect in pp/pA collisions [12–14] due to the initial state parton effects. However, these models do not explain the anomalous variation with the charged multiplicity density of the midrapidity strange particle production and of $\langle p_T \rangle$.

The QGP formation in pp/pA collisions should lead to jet modification due to parton energy loss in the QGP fireball. It is important that the typical charged multiplicity of soft (underlying event (UE)) hadrons in jet events is bigger than the ordinary minimum bias multiplicity by a factor of $\sim 2-2.5$ [15]. For the LHC energies the typical midrapidity UE charged multiplicity $dN_{ch}^{ue}/d\eta \sim 10-15$ in pp jet events. One of the possible experimental methods to probe jet quenching in the small size QGP produced in pp/pA collisions is investigation of the UE multiplicity dependence of the jet fragmentation functions (FFs) for photon/hadron tagged jets [16] described by the modification factors $I_{pp/pA}$. Formally, $I_{pp,pA}$ can be defined as the ratio of the per-trigger particle (h^t) yield of the associated hadron (h^a) production, $Y_{pp,pA}$, to the yield for pp collisions calculated without the medium effects, Y_{pp}^0. However, Y_{pp}^0 is unobservable quantity. For this reason, it is convenient to characterize the medium effects in pc collisions in terms of the UE multiplicity dependence of the ratio of the experimental yields Y_{pc} and the average yield for pp collisions $\langle Y_{pp} \rangle$

$$\frac{Y_{pc}(\{p_T\},\{y\})}{\langle Y_{pp}(\{p_T\},\{y\})\rangle}\,, \tag{1}$$

where $\{p_T\} = (p_T^a, p_T^t)$ and $\{y\} = (y^a, y^t)$ are the sets of the transverse momenta and rapidities of the trigger particle and the associated hadron, and $\langle ... \rangle$ means averaging over the UE multiplicity. In terms of the modification factors I_{pc} (defined via the unobservable yield Y_{pp}^0) the ratio (1) should be equal to the ratio $I_{pc}/\langle I_{pp} \rangle$. Recently, the ALICE collaboration [17, 18] measured the UE multiplicity dependence of the ratio (1) for the hadron tagged jets in pp and $p+\mathrm{Pb}$ collisions at $\sqrt{s} = 5.02$ TeV. The ALICE [18] measurement has been performed for the hadron momenta $8 < p_T^t < 15$ GeV, $4 < p_T^a < 6$ GeV, and the UE activity has been characterized by the charged multiplicity N_{ch}^T in the transverse kinematical region $\pi/3 \le |\phi| \le 2\pi/3$, $|\eta| < 0.8$, and $p_T > 0.5$ GeV. As compared to the UE charged multiplicity density $dN_{ch}^{ue}/d\eta$, defined in the whole ϕ and p_T regions for the pseudorapidity window $|\eta| < 0.5$, N_{ch}^T of [17, 18] is smaller by a factor of ≈ 4.4. For pp collisions, in [19] it was found that I_{pp} decreases by

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about 7–10 % with increase of the UE activity in the range $5 \lesssim dN_{ch}/d\eta \lesssim 20$ for the jet quenching calculated within the light-cone path integral formalism [20–23] for the induced gluon emission. The results of [17] for $I_{pp}/\langle I_{pp}\rangle$ agree qualitatively with calculations of [19]. It would be interesting to perform calculation of I_{pA} and comparison with data from [18] as well. The data of [18] for Y_{pA} also show a tendency of some decrease of Y_{pA} with increasing the UE charged multiplicity. But the effect seems to be somewhat smaller, at least visually, than that observed for pp collisions. However, one should bear in mind that in the case of pA collisions the observed UE charged multiplicity density may contain a considerable fraction of hadrons that come from interaction of the projectile with peripheral nucleons without the formation of the collective QCD matter. Because interaction with the peripheral nucleons may produce low density/entropy parton system, for which the energy/entropy density is not large enough to form the QGP. Thus, one can expect that the fireball of the QCD matter in pA collisions should have the core-corona structure (discussed previously for AA collisions [24]). The effect of hadrons from the corona region on jet quenching should be small since these hadrons should be in the free streaming regime. For this reason, for the jet quenching calculation of the variation of I_{pA} with the observed UE charged multiplicity $dN_{ch}^{ue}/d\eta$ one needs a formalism for accounting for the difference between the observed $dN_{ch}^{ue}/d\eta$ and the charged multiplicity related to formation of the QGP fireball. In the present paper we perform such jet quenching calculations of I_{pA} for conditions of the ALICE experiment [17] using the Monte-Carlo (MC) Glauber model of [25] for calculation of the QGP fireball parameters as a function of the total UE charged multiplicity density. The parameters of the QGP fireball depends on the free parameters of the MC Glauber model. However, our results demonstrate that predictions for I_{pA} turn out to be quite stable to the theoretical uncertainties of the MC Glauber scheme. The medium-modified FFs have been evaluated within the light-cone path integral approach to induced gluon emission [20–23]. We used parametrization of the running QCD coupling $\alpha_s(Q,T)$ which has a plateau around $Q \sim \kappa T$ (motivated by the lattice simulations [26]). The value of κ is fitted to the LHC data on the nuclear modification factor R_{AA} in 2.76 and 5.02 TeV Pb + Pb, and 5.44 TeV Xe + Xe collisions. Our calculations show that the jet quenching effect for I_{pA} turns out to be rather small: the ratio $I_{pA}/\langle I_{pp}\rangle$ falls from ~ 1.03 at $dN_{ch}^{ue}/d\eta \sim 10$ to ~ 0.95 at $dN_{ch}^{ue}/d\eta \sim 60$. This, within errors, agrees with data from ALICE [18] for 5.02 TeV p + Pb collisions. However, the experimental errors are too large to draw a firm conclusion on the possible presence of jet quenching.

Funding. This work is supported by Russian Science Foundation grant # 20-12-00200 in association with Steklov Mathematical Institute.

Conflict of interest. The author of this work declares that he has no conflicts of interest.

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