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Double nuclear modification factor in relativistic heavy ion collisions

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The hypothesis of the factorization of the double nuclear modification factor in relativistic heavy ion collisions is tested for different types of final-state hadrons within the HYDJET++ model. The results demonstrate that this factorization holds reasonably well at moderately high transverse momenta, provided that the effects of double parton scattering can be small or neglected.

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In a recent study [1], a novel observable, the double nuclear modification factor, was proposed as a tool to simultaneously probe initial and final state effects in relativistic nucleus-nucleus collisions. The interplay between double parton scattering and jet quenching effects was illustrated in a simplified scenario where one of the two hard particles propagates through the dense medium without energy loss. In this work, we extend the analysis to a more general case in which both hard particles experience energy loss.

The experiments at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) have yielded a wealth of information about the properties of dense and hot matter created in heavy ion collisions (see, e.g., [2] and references therein). One prominent phenomenon is jet quenching due to medium-induced partonic energy loss [3–5]. The observable most directly associated with jet quenching is the suppression of the yield of hadrons with a high transverse momentum p_T, which is quantified by the nuclear modification factor, $R_{AA}(p_T, \eta)$. It is defined as the ratio of the inclusive single-hadron yield per unit pseudorapidity η in A-A collisions to the corresponding yield in pp collisions, scaled by the average number of binary nucleon-nucleon collisions $<N_{\rm coll}>$:

$$R_{AA}(p_T, \eta) = \frac{d^2N_{AA}/dp_T d\eta}{<N_{\rm coll}> d^2N_{pp}/dp_T d\eta}. \tag{1}$$

If there are no nuclear effects, the value R_{AA} at high p_T should be unity. R_{AA} can be thought of as the survival probability of a particle produced within a nuclear medium. This probability depends not only on energy loss, but also on the spectrum of hard partons produced with respect to their transverse momentum [6].

One can generalize this nuclear modification factor to the case of two hard produced partons (particles) by introducing a double nuclear modification factor [1]:

$$R_{AA}(p_{T1}, \eta_1; p_{T2}, \eta_2) = \\ = \frac{d^4N_{AA}/dp_{T1}d\eta_1 dp_{T2}d\eta_2}{<N_{\rm coll}> d^4N_{pp}/dp_{T1}d\eta_1 dp_{T2}d\eta_2}. \tag{2}$$

If we assume that the two hard partons do not interact with each other after production and the two final particles are produced through independent hadronization from two separate jets, we can arrive at a naive expectation that the survival probability will be factorized. In practice, the assumption of independent survival probabilities for hard partons may not hold. Then a numerical prefactor F characterizing the deviation from the factorization is introduced [1]:

$$R_{AA}(p_{T1}, \eta_1; p_{T2}, \eta_2) = F \cdot R_{AA}(p_{T1}, \eta_1) \cdot R_{AA}(p_{T2}, \eta_2). \tag{3}$$

The main purpose of this work is to estimate the prefactor F in a model that deals with jet quenching effect. The HYDJET++ model [7] is well suited for this purpose, because the large number of physical observables measured in heavy ion collisions during RHIC and LHC operation are successfully described within this framework [8–13]. The HYDJET++ includes two independent components that describe soft and hard processes, respectively. For soft processes, HYDJET++ employs an adapted version of the FAST MC model [14, 15], which is based on a relativistic hydrodynamic parameterization of chemical and thermal freeze-out hypersurfaces. To simulate anisotropic flow, a hydro-inspired parameterization of the momentum

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and spatial anisotropy of soft hadron emission sources is implemented [7, 16]. For hard processes, partonic energy loss model PYQUEN [17] is used. The recent HYDJET++ developments and results may be found in [18–20].

The inclusive single and double yields of pions, kaons and protons at $|\eta| < 1$ for 5 % most central Pb + Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV were simulated taking into account jet quenching and nuclear shadowing effects. The p_T-dependences of F for different types of final-state hadrons are similar (Fig. 1). The deviation F from factorization for a double nuclear modification factor is observable, although it remains relatively small, consistent with the assertion $F = \mathcal{O}(1)$. The growth of F with increasing p_T can be explained by a greater contribution from back-to-back initial hard parton configurations, along with a reduced p_T-imbalance.

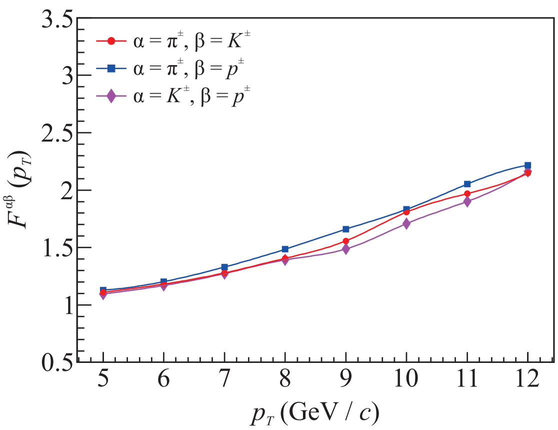

Fig. 1. (Color online) The dependence of the ratio F of the double and the product of single nuclear modification factors on the minimum value of the hadron transverse momentum p_T

To summarize, our results indicate that the hypothesis of factorization holds reasonably well at moderately high p_T, provided that the effects of double parton scattering can be small or neglected. However, factorization violation starts to show at very high p_T. So we conclude that measurements of the double nuclear modification factors offer significant potential for further investigations. These studies can be extended to various types of hard final-state particles across a broad range of transverse momenta.

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