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Probing transverse momentum broadening via jet-related angular correlations in relativistic nuclear collisions

Lin Chen, Guang-You Qin, Shu-Yi Wei, Bo-Wen Xiao, Han-Zhong Zhang

Institute of Particle Physics and Key Laboratory of Quark and Lepton Physics (MOE), Central China Normal University, Wuhan, Hubei, 4.8879, China

Abstract

Jet-related correlations have been regarded as important tools for studying jet-medium interaction and jet quenching in relativistic heavy-ion collisions at RHIC and the LHC. Here we present our recent work [1] and show that the back-to-back angular correlations in dijet, dihadron and hadron-jet measurements can be utilized as a quantitative tool to probe the medium-induced transverse momentum broadening and to extract jet quenching parameter $\hat{q}$. By comparing with the dihadron and hadron-jet angular correlation data at RHIC, we obtain the medium-induced transverse momentum broadening, averaged over different jet paths, $\langle p_\perp^2 \rangle \sim 13$ GeV^2 for a quark jet in most central Au-Au collisions at 200A GeV. Future experiments with statistically improved data on jet-related (angular) correlations will allow us to obtain more precise knowledge of jet quenching parameter and parton-medium interaction in high-energy nuclear collisions.

Keywords:
Heavy-ion collisions, Quark-gluon plasma, Jet-medium interaction, Jet-related correlations, Jet quenching (parameter)

1. Introduction

Jet quenching is one of the most important evidences for the formation of quark-gluon plasma (QGP) and has been regarded as a useful tool to study the novel properties of QGP in relativistic heavy-ion collisions performed at the Relativistic Heavy-Ion Collider (RHIC) and the Large Hadron Collider (LHC) [2, 3]. When a pair of high-energy jets that are produced in early hard collisions traverse the QGP, they interact with the medium via elastic and inelastic interactions and get modified during the process. Various studies of large transverse momentum hadrons and full jets at RHIC and the LHC have shown that the hard jet partons may experience a significant amount of energy loss during their interaction with the hot QGP [4, 5, 6, 7, 8]. Jet-medium interaction also induces transverse momentum broadening on the propagating jets which may manifest as the decorrelation of jet-related (e.g., dijet, γ-jet, dihadron, γ-hadron and hadron-jet) back-to-back angular distributions. In fact, these two aspects, i.e., parton energy loss and transverse momentum broadening, are closely related. For example, in BDMPS [9] and higher-twist [10] formalisms, the radiative gluon spectrum (energy loss) is directly controlled by jet quenching parameter $\hat{q} = d\langle p_\perp^2 \rangle/dt$, which quantifies the rate of transverse momentum broadening and relates to the local density of QGP. Due to the significance of $\hat{q}$, it now becomes one of the important tasks to quantitatively extract the $\hat{q}$ value in many jet quenching studies. The first systematic effort was performed by JET collaboration who have studied the

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effect of parton energy loss and extracted the value of $\hat{q}$ by comparing several jet quenching model calculations of single inclusive hadron suppression to RHIC and the LHC data [6]. Here we present our recent work [1] and show that one may utilize jet-related back-to-back angular correlations as a new quantitative tool to extract the medium-induced transverse momentum broadening and jet quenching parameter $\hat{q}$.

2. Jet-related back-to-back angular correlations

Jet-related correlations have been extensively studied since the start of RHIC and are important tools for studying jet quenching in heavy-ion collisions. However, most studies focus on the medium modifications of the (per-trigger) yield and transverse momentum imbalance caused by parton energy loss [11, 12, 13, 14, 15]. Our calculation of jet-related back-to-back angular correlations is based on Refs. [16, 17, 18, 19, 20] in which the Sudakov resummation framework has been built to describe dijet angular correlations in pp and AA collisions. By convoluting with fragmentation functions and taking the proper Sudakov factors associated with final state gluon radiations, we apply the Sudakov resummation framework to compute dihadron and hadron-jet angular correlations. The differential cross-section for dihadron production at mid-rapidity in relativistic nuclear collisions can be obtained as follows [1]:

$$\begin{aligned}\frac{d\sigma}{p_T^{h_1} dp_T^{h_1} p_T^{h_2} dp_T^{h_2} d\Delta\phi} &= \sum_{a,b,c,d} \int \frac{dz_c}{z_c^2} \int \frac{dz_d}{z_d^2} \int bdb\, J_0(q_\perp b) e^{-S(Q,b)} x_a f_a(x_a,\mu_b) x_b f_b(x_b,\mu_b) \\ &\times \frac{1}{\pi} \frac{d\sigma_{ab\to cd}}{d\hat{t}} D_c(z_c,\mu_b) D_d(z_d,\mu_b). \qquad (1)\end{aligned}$$

Similar expressions can be written for dijet and hadron-jet productions. Here, $J_0(q_\perp b)$ is the Bessel function of the first kind with $\vec{q}_\perp \equiv \vec{p}_T^{\,c} + \vec{p}_T^{\,d}$ the dijet transverse momentum imbalance and $\vec{b}$ the Fourier transform of $\vec{q}_\perp$. $S(Q,b)$ is the Sudakov factor with the hard scale $Q = \sqrt{x_a x_b s_{NN}}$. $f_{a,b}(x_{a,b},\mu_b)$ are the parton distribution functions with $x_{a,b} = \max(p_T^c, p_T^d)(e^{\pm y_c} + e^{\pm y_d})/\sqrt{s_{NN}}$, $\frac{d\sigma}{d\hat{t}}$ is the leading order partonic cross-section, and $D_{c,d}(z,\mu_b)$ are the fragmentation functions with $z_{c,d} = p_T^{h_1,h_2}/p_T^{c,d}$. In the above expression, all the factorization scales are taken to be $\mu_b = 2e^{-\gamma_E}/b_*$ with $b_* \equiv b/\sqrt{1 + b^2/b_{\max}^2}$ by following the so-called b_* prescription in the derivations of the Sudakov resummation formalism [21]. The vacuum contribution to the Sudakov factor can be factorized into perturbative and non-perturbative parts [16, 17, 18]:

$$S_{\rm vac}(Q,b) = S_{\rm p}^{i}(Q,b) + S_{\rm p}^{f}(Q,b) + S_{\rm np}(Q,b). \qquad (2)$$

In the presence of QCD medium, the contribution from medium-induced transverse momentum broadening to the angular correlations can be incorporated into the Sudakov formalism as follows: [19, 20]:

$$S_{\rm med}(Q,b) = S_{\rm vac}(Q,b) + \frac{b^2}{4}\frac{1}{2}\left(\langle p_\perp^2\rangle_c + \langle p_\perp^2\rangle_d\right). \qquad (3)$$

Here, $\langle p_\perp^2\rangle_{c,d}$ denotes the medium-induced broadening experienced by each outgoing jet (averaged over different jet paths). The factor $\frac{1}{2}$ is applied in central rapidity region since only half of the medium-induced broadening contributes to the azimuthal de-correlation while the other half goes into the beam direction.

In Fig. 1, we show our calculations of dihadron angular correlations at RHIC and compare to PHENIX [22] and STAR [23] data. We can see that the Sudakov resummation formalism as developed above can provide reasonable descriptions of pp dihadron angular correlation data for various transverse momentum cuts. This sets the baseline for studying the medium-induced transverse momentum broadening effect in AA collisions. We can see that the medium-induced broadening effect further flattens the dihadron angular distributions. Using $\langle p_\perp^2\rangle \sim 13$ GeV^2 for medium-induced broadening, the dihadron angular correlation data in Au-Au collisions at 200A GeV from PHENIX and STAR can be described quite well. In Fig. 2, we show our calculations of hadron-jet angular correlations at RHIC and the LHC, and compare to recent measurements from STAR and ALICE Collaborations [24, 25]. One can see that due to the large vacuum Sudakov effect at the LHC, hadron-jet angular correlations measured by the ALICE are not very sensitive to additional medium broadening effect. In contrast, hadron-jets measured by STAR are quite sensitive to the medium effect since vacuum radiation effect is smaller at RHIC. By comparing with STAR hadron-jet angular correlation data, similar value for the medium broadening $\langle p_\perp^2\rangle \sim 13$ GeV^2 is obtained.