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Probing jet medium interaction from dijet and photon-jet transverse momentum imbalances

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In the recent two papers [1, 2], we establish the Sudakov resummation improved perturbative QCD calculation approach to quantitatively study the dijet and photon-jet transverse momentum imbalances in high energy proton-proton collisions. The hard splittings have been taken into account by the next-to-leading order calculation in perturbative QCD, while, the soft gluon radiations (parton shower) have been taken care of by the Sudakov resummation. Based on BDMPS energy loss approach, we calculate the transverse momentum imbalances in the nucleus-nucleus collisions as well and extract the value of $\hat{q}$. This proceeding is a summary of these two papers.

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1. Introduction

The jet quenching phenomenon is one of the strongest evidences for the presence of the quark-gluon-plasma (QGP) in relativistic heavy-ion collisions [3, 4]. In the past decades, theorists and experimentalists have been working closely to reveal the properties of QGP and quite a lot of remarkable progresses have been achieved.

The nuclear suppression factor for single inclusive hadron/jet production, which encodes the information about how much energy has been lost when the jets traverse through the QGP, has been measured by experimentalists at both RHIC [5, 6] and the LHC [7, 8, 9, 10, 11]. Theorists have been working with several energy loss models to quantitatively study the jet-medium interaction. As one of the most impressive achievements, the jet transport coefficient $\hat{q}$ has been extracted from the nuclear modification factor of the single inclusive hadron production by the JET collaboration [12]. However, since the nuclear modification in nucleus-nucleus collisions integrates many effects, the nuclear suppression factor alone has limited power. It can give us a glimpse of what is going on inside of the medium, but it is not able to decide which energy loss model tells a better story.

In order to gather more information about jet-medium interaction, we need to go beyond single inclusive observables. For instance, the dihadron and hadron jet angular decorrelations in the nucleus-nucleus collisions, as a direct consequence of the transverse momentum broadening effect, have been measured [13, 14, 15, 16]. The averaged value of the transverse momentum broadening square has been extracted quantitatively [17] from these measurements. In contrast with the nuclear suppression factor, the angular decorrelation does not heavily rely on the energy loss effect and hence becomes a new aspect of the jet quenching study.

In this proceeding, we will briefly present our work on the correlation of transverse momenta in dijet and photon-jet production processes [1, 2].

2. Sudakov resummation and fixed order calculation

The dijet or photon-jet transverse momentum imbalance is usually defined as the ratio of the transverse momentum of an associate jet, which satisfies the given kinetic requirements, with that of the leading jet (or photon) [18, 19]. $x_J \equiv p_{T2}/p_{T1}$. In the dijet case, only the leading and sub-leading jets are measured. For the photon-jet production, all the jets located in the azimuthally back-to-back of the photon contribute.

When $\vec{p}_{T1}$ and $\vec{p}_{T2}$ are back-to-back with similar magnitudes, $\vec{q}_T \equiv \vec{p}_{T1} + \vec{p}_{T2} \to 0$. The large Sudakov double logarithms arising from soft gluon radiations will appear in the fixed order calculation which breaks the predictive power of the perturbative expansion. The resummation of the logarithms is therefore mandatory to give reliable predictions [20]. However in the case that q_T is very large, the non-logarithm terms in the fixed order calculation become important. Hence in order to calculate the x_J distribution in the full kinematic region, both formalisms are called for. Several approaches have been made, for the sake of that one can match these two formalisms together smoothly. This is certainly a topic of interest, but not our main point in this proceeding.

In our work, we employ a simple but quite effective method. As illustrated in Fig. 1, a matching point ϕ_m is chosen to separate the phase space. When $\Delta\phi$ is larger than ϕ_m, the Sudakov resummation is turned on. The fixed order calculation will be in charge in the region $\Delta\phi < \phi_m$. In this way, all-order soft gluon radiations have been taken care of by the Sudakov resummation, while the fixed-order hard splittings have been taken into account by the next-to-leading order calculation in perturbative expansion.

$$\frac{1}{\sigma}\frac{d\sigma}{dx_J}\bigg|_{\text{improved}} = \frac{1}{\sigma_{\text{fixed order}}}\frac{d\sigma_{\text{fixed order}}}{dx_J}\bigg|_{\Delta\phi<\phi_m} + \frac{1}{\sigma_{\text{resummed}}}\frac{d\sigma_{\text{resummed}}}{dx_J}\bigg|_{\Delta\phi>\phi_m}. \tag{2.1}$$

We have a few comments on Eq. 2.1: (1) Since both formalisms are properly normalized, the sum of these two is approximately normalized to unity (this has been checked numerically). (2) Our approach does not strongly depend on the choice of matching point, since there is a large overlapping region in which both Sudakov resummation and next-to-leading order calculation can describe the experimental data. ϕ_m is therefore actually not a free parameter.

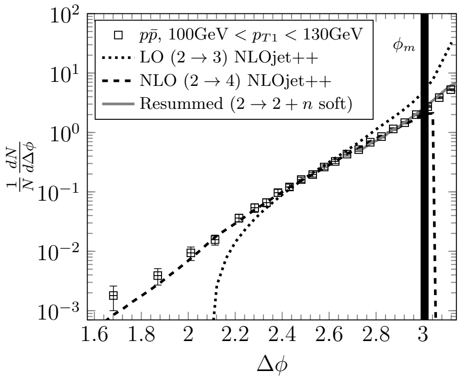

Figure 1: Matching of Sudakov resummation and fixed order calculation using the phase space separation. Experimental data come from Ref. [21].

3. Unfolding and smearing

We want to note here that the detector response effect can significantly change the x_J distribution measured in the experiments. The procedure to correct this effect is called unfolding [19]. The narrow peak at $x_J \sim 1$ disappears, if the unfolding procedure has not been performed. We need to keep in mind that only the fully corrected experimental data can be compared with the theoretical results directly. In order to compare with the uncorrected data, we need to include the detector response effect in the theoretical calculation, namely convolute with a smearing function.

For the photon-jet production, we can easily parameterize the one-dimensional smearing function in the following way,

$$\frac{d\sigma}{dp_\perp} = \int \frac{dr}{\sqrt{2\pi}\sigma}\exp\left[-\frac{r-\bar{r}}{2\sigma^2}\right]\frac{1}{r}\frac{d\sigma}{dp'_\perp}\bigg|_{p'_\perp=p_\perp/r}. \tag{3.1}$$

Where, $p_\perp$ is the transverse momentum of the jet measured by the detectors; $p'_\perp$ is the true transverse momentum; $\bar{r}$ and σ are the parameters determined by the detectors. While, for the dijet production process, a two-dimensional smearing matrix is required, which complicates the situation.

4. Numerical results

In this section, we show the numerical results calculated from the resummation improved perturbative QCD approach and compare with the experimental data in Fig. 2. When we published our paper, the fully corrected data for the photon-jet production process was not available yet. Therefore we use Eq. 3.1 to simulate the detector response effect.

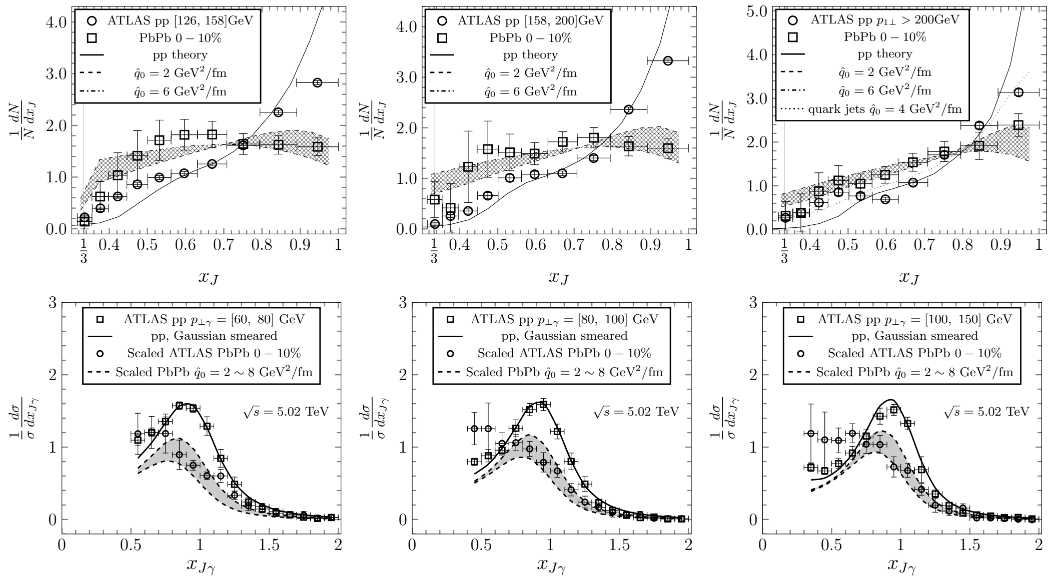

Figure 2: The upper panel is the transverse momentum imbalance for dijet production compared with the fully corrected data from ATLAS collaboration [18]. The lower panel is that for the photon-jet production compared with the uncorrected data from the ATLAS collaboration [22].

In the BDMPS energy loss approach [23], the probability distribution for a jet to loss energy ε is, $D(\varepsilon) = \frac{1}{\varepsilon}\sqrt{\frac{\alpha^2\omega_c}{2\varepsilon}}\exp\left(-\frac{\pi\alpha^2\omega_c}{2\varepsilon}\right)$. Here, ω_c is $\hat{q}L$ integrated over the propagation path L. The jet transport coefficient $\hat{q}$ is then extracted through comparing with the experimental data in central nucleus-nucleus collisions at different center-of-mass energies.

5. Summary

We establish the resummation improved perturbative QCD approach to calculate the dijet and photon-jet transverse momentum imbalances. We find $\hat{q}_0 = 2-6$ GeV^2/fm at $T_0 = 481$ MeV and $\hat{q}_0 = 2-8$ GeV^2/fm at $T_0 = 509$ MeV, using the BDMPS approach for the energy loss calculations.

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