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A study of γ-hadron correlation in p + Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV

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Under the assumption that a quark-gluon plasma droplet is created in p + A collisions and partons traversing it will lose their energy, we calculate γ-triggered hadron correlation in p + Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, within a next-to-leading-order perturbative QCD parton model with the medium-modified fragmentation functions. The parton energy loss can be controlled by the scaled jet transport coefficient $\hat{q}/T^3$ within the high-twist (HT) approach. The evolution informations of such QGP medium created in p + A collisions are provided by the SuperSONIC hydrodynamics model. With the value of $\hat{q}/T^3$ extracted via single hadron suppressions in A + A collisions with similar highest initial temperature as in p + A collisions, the γ-hadron spectra with $p_{\rm T}^{\gamma}$ = 12 – 40 GeV/c show a suppression of 5%~10% in the most central 0 - 10% p + Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. We also provide the predictions for γ-hadron suppression in Pb + Pb collisions at the LHC energies.

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1. Introduction

It is generally believed that γ-jet production is a golden probe for studying the parton energy loss [1] in high-energy heavy-ion collisions. If we assume that a small QGP droplet is produced in p + A collisions and its evolution can be described by hydrodynamics, we can also predict suppression of γ-hadron production with medium-modified fragmentation functions. We assume that partons will lose their energy when traversing such a medium and the lost energy is controlled by the jet transport coefficient $\hat{q}$ [2] which is defined as the transverse momentum broadening squared per unit length. It depends on medium temperature T and four fluid velocity u^{μ} in the form $\hat{q} = \hat{q}_0 \frac{\mathrm{T}^3}{\mathrm{T}_0^3} \frac{p^{\mu} \cdot u^{\mu}}{p_0}$, where T_0 is the highest temperature at the center of the medium at the initial time τ_0 for the QGP formation. The information for T and u^{μ} are given by event-by-event simulations of the superSONIC hydrodynamic model[3, 4]. In our last work [5], we find that the scaled dimensionless initial jet transport coefficient $\hat{q}/T^3$ is decreasing slightly with the initial temperature. So we believe that the same value of jet transport coefficient can be approximatively applied for γ-hadron in p + A collisions as obtained for single hadron in A + A collisions at the similar initial temperature of the created QGP mediums.

2. The theory model

In p +A collisions, γ-hadron cross section can be expressed as,

$$\frac{d\sigma_{pA}^{\gamma h}}{dy^{\gamma} d^2 p_{\rm T}^{\gamma} dy^h d^2 p_{\rm T}^h} = \sum_{abd} \int d^2 r dz_d t_A(\vec{r}) f_{a/A}(x_a, \mu^2, \vec{r}) f_{b/p}(x_b, \mu^2) \frac{x_a x_b}{\pi z_d^2}$$
$$\times \frac{d\sigma_{ab\to\gamma d}}{d\hat{t}} \tilde{D}_{h/d}(z_d, \mu^2, \Delta E_d) \; + O(\alpha_e \alpha_s^2), \tag{1}$$

where $f_b/p(x_b, \mu^2)$ and $f_a/A(x_a, \mu^2, \vec{r})$ are the parton distribution functions and $t_A(\vec{r})$ is the nuclear thickness function. $d\sigma_{ab\to\gamma d}/d\hat{t}$ are the tree-level $2 \to 2$ partonic scattering cross sections. The NLO correction at $O(\alpha_e \alpha_s^2)$ order included in our calculation contains $2 \to 2$ virtual diagrams and $2 \to 3$ tree diagrams. We only focus on direct photons which come from the hard processes of the Compton ($qg \to q\gamma$) or annihilation ($q\bar{q} \to g\gamma$) scattering. With isolation cuts the contribution from fragmentation photons is only about 10%. We can ignore them here [7].

The medium-modified fragmentation function $\tilde{D}_{h/d}(z_d, \mu^2, \Delta E_d)$ can be expressed as [6],

$$\tilde{D}_{h/d}(z_d, \mu^2, \Delta E_d) = (1 - e^{-\langle N_g^d \rangle}) \left[\frac{z_d'}{z_d} D_{h/d}(z_d', \mu^2) + \langle N_g^d \rangle \frac{z_g{}'}{z_d} D_{h/g}(z_g{}', \mu^2) \right]$$
$$+ e^{-\langle N_g^d \rangle} D_{h/d}(z_d, \mu^2). \tag{2}$$

With the high-wist formalism [8], the radiative energy loss ΔE_d can be calculated as,

$$\frac{\Delta E_d}{E} = \frac{2 C_A \alpha_s}{\pi} \int d\tau \int \frac{dl_{\rm T}^2}{l_{\rm T}^4} \int dz \times \left[1 + (1-z)^2\right] \hat{q}_d \sin^2 \left[\frac{l_{\rm T}^2 (\tau - \tau_0)}{4z(1-z)E} \right], \tag{3}$$

where $C_A = 3$, $l_{\rm T}$ is the transverse momentum of the radiated gluon.

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Using the spectrum in p + p collisions as a baseline, the gamma-hadron nuclear modification factor $I^{\gamma h}_{pA}(z_{\rm T}) = \frac{D^{\gamma h}_{pA}(z_{\rm T})}{D^{\gamma h}_{pp}(z_{\rm T})}$ can be expressed as a function of $z_{\rm T} = p^h_{\rm T}/p^\gamma_{\rm T}$ [9] . $D^{\gamma h}_{pA}(z_{\rm T})$ is the γ-triggered fragmentation function which can be defined as the ratio of γ-hadron cross section to the trigger photon cross section.

3. Numerical results

We first calculate the $\gamma^{\rm dir}$-triggered fragmentation function in p + p collisions at $\sqrt{s_{\rm NN}}$ = 0.2 TeV and the corresponding medium modification factor $I^{\gamma h}_{AuAu}$ in 0 - 10% Au + Au collisions. Both of them agree well with the experimental data. The details are shown in our recent paper [10]. The predictions for γ-hadron suppression $I^{\gamma h}_{PbPb}$ in Pb + Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV and 5.02 TeV for different (0 - 5%, 20 - 30%, 40 - 50%, 60 - 70%) centralities are shown in Fig. 1. The corresponding $\hat{q}_0$ = 1.8 GeV^2/fm in Pb + Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV and $\hat{q}_0$ = 2.0 GeV^2/fm in Pb + Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV are extracted via comparisons to single inclusive hadron suppressions in 0 - 5% Pb + Pb collisions at these two energies, respectively [10].

Shown in Fig. 2 are our predictions for $I^{\gamma h}_{pPb}$ in p + Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with $\hat{q}_0$ = 1.5 GeV^2/fm which is extracted from single hadron production in Au + Au collisions at $\sqrt{s_{\rm NN}}$ = 0.2 TeV which have the similar central temperature as in p + Pb collisions. The shaded bands indicate variations of the results when one changes the initial time for parton-medium interaction between τ_0 = 0.5 and 1.0 fm/c. For γ-hadron spectra in p + Pb collisions, we see a suppression of about 5%~10% due to jet quenching. In both Pb + Pb and p + Pb collisions, the suppression of γ-triggered hadron spectra becomes weaker with a larger $p_{\rm T}$ trigger photon.

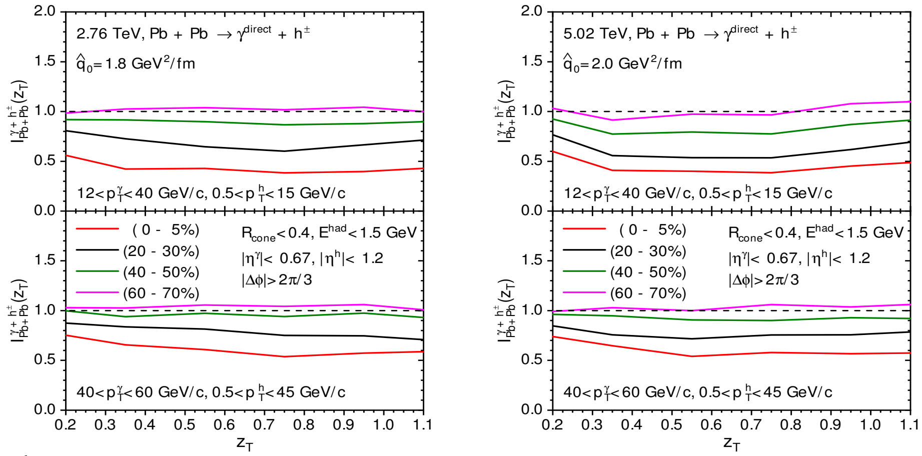

Figure 1: $\gamma^{\rm dir}$-hadron suppression factors as a function of $z_{\rm T}$ in 0 - 5%, 20 - 30%, 40 - 50% and 60 - 70% Pb + Pb collisions, with 12 < $p^\gamma_{\rm T}$ < 40 GeV/c, 0.5 < $p^h_{\rm T}$ < 15 GeV/c (upper panels) and 40 < $p^\gamma_{\rm T}$ < 60 GeV/c, 0.5 < $p^h_{\rm T}$ < 45 GeV/c (lower panels) at $\sqrt{s_{\rm NN}}$ = 2.76 TeV with $\hat{q}_0$ = 1.8 GeV^2/fm (left panels) and at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with $\hat{q}_0$ = 2.0 GeV^2/fm (right panels).

4. Summary

Under the assumption that a QGP droplet is produced in p + Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV and its evolution can be described by hydrodynamics, we predict the suppression of γ-triggered

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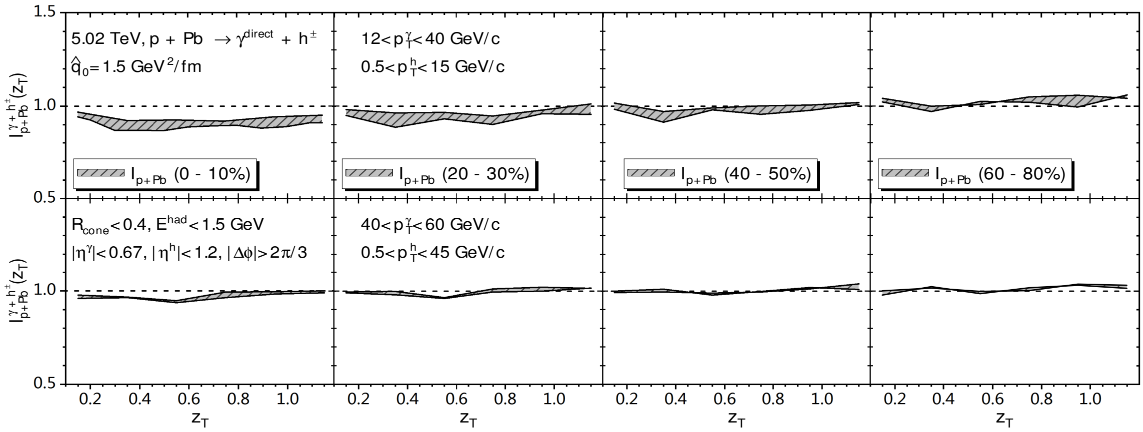

Figure 2: $\gamma^{\rm dir}$-hadron suppression factors as a function of $z_{\rm T}$ in 0 - 10%, 20 - 30%, 40 - 50% and 60 - 80% p + Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with $12 < p_{\rm T}^{\gamma} < 40$ GeV/c, $0.5 < p_{\rm T}^{h} < 15$ GeV/c (upper panels) and $40 < p_{\rm T}^{\gamma} < 60$ GeV/c, $0.5 < p_{\rm T}^{h} < 45$ GeV/c (lower panels). The shaded bands indicate variations of the results when one changes the initial time for parton-medium interaction between $\tau_0 = 0.5$ and 1.0 fm/c.

hadron spectra within NLO perturbative QCD parton model with medium modified fragmentation function due to parton energy loss. The parton energy loss is calculated with the high-twist formalism. The evolution information of the medium created in p + Pb collisions are provided by event-by-event superSONIC hydrodynamics model. Our numerical results show a suppression of about 5%∼10% for γ-hadron spectra for $12 < p_{\rm T}^{\gamma} < 40$ GeV/c in the most 0 - 10% central p + Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with the initial jet transport coefficient $\hat{q}_0$ extracted from the suppression of single hadron spectra in A + A collisions. And we also predict the γ-hadron productions in Pb + Pb collisions at the LHC energies.

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