Physics Letters B 724 (2013) 278–282

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Towards detailed tomography of high energy heavy-ion collisions by γ-jet

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ARTICLE INFO

Article history:
Received 12 April 2013
Received in revised form 28 May 2013
Accepted 17 June 2013
Available online 19 June 2013
Editor: W. Haxton

Keywords:
γ-Jet imbalance
Detailed tomography
Parton cascade

ABSTRACT

Within a multi-phase transport (AMPT) model with string melting scenario, the transverse momentum imbalance between prompt photon and jet is studied in Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Jet loses more energy in more central collisions due to strong partonic interactions between jet parton shower and partonic matter, which is more significant than due to hadronic interactions only. The hadronization and final-state hadronic interactions have little influences on the imbalance. The imbalance ratio $x_{j\gamma}$ is sensitive to both production position and passing direction of γ-jet, which provides an opportunity to do detail γ-jet tomography on the formed partonic matter by selecting different $x_{j\gamma}$ ranges. It is also proposed that γ-hadron azimuthal correlation associated with photon + jet is a probe to see the medium responses to different γ-jet production configurations.

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1. Introduction

Measurements of jets produced in hard scattering processes serve as an important probe of the strongly interacting partonic matter at RHIC and LHC which can help investigate the properties of the formed new matter [1,2]. Many experimental observables show that jets lose their energies significantly because they have to interact with the hot and dense medium when they pass it through [3,4]. Recent experimental results based on full jet reconstruction disclose more detailed characterizations of jet-medium interactions [5,6]. Prompt photon and jet, i.e. γ-jet, can be produced by a initial hard scattering process with similar large transverse momentum (p_T) back-to-back-ly at leading order. Recent results from PHENIX show that direct photons with high p_T do not flow [7] and their nuclear modification factor R_{AA} is around unity [8], which is consistent with the picture that they are dominantly produced in initial hard scatterings and do not participate in strong interactions due to their neutral electric and color charges. γ-triggered correlation has been proposed as a golden channel for jet physics, since it brings a different kinematical and geometrical bias in comparison with jet-triggered one [9], although it costs all additional information from the photon trigger. Recently, lots of experimental efforts have been invested in measuring reconstructed jets in high energy heavy-ion collisions. The photon + jet measurements from CMS and ALTAS provide direct and less biased quantitative measures of jet energy loss in the medium, which give a deceasing jet-to-photon momentum imbalance ratio ($x_{j\gamma}$) from peripheral to central centrality bin in Pb + Pb collisions at LHC energy [10,11]. Some theoretical attempts have been made to understand it. Vitev and Zhang evaluated the transverse momentum imbalance of photon + jet is induced by the dissipation of parton shower energy due to strong final-state interactions [12]. Qin found that photon-tagged jet has a sensitivity on production position of γ-jet and propose it as a tomographic tool for studying jet quenching in heavy-ion collisions [13]. In this Letter, a detail tomographic analysis with photon + jet are performed in Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV within a multi-phase transport (AMPT) model with string meting scenario. The large imbalance of photon + jet can be produced by strong interactions between jet parton shower and partonic medium. Because the momentum imbalance is sensitive to both production position and passing direction of γ-jet, it makes it possible to use photon + jet as a probe to do a detailed tomography on the partonic matter created in high energy heavy-ion collisions.

The Letter is organized as follows. In Section 2, I give a brief description of AMPT model and jet physics inside, and introduce the analysis method for γ-jet reconstruction. Results on γ-jet imbalance are presented in Section 3 and then a possible detailed tomography with γ-jet is discussed in Section 4. Finally a summary is given in Section 5.

2. Model introduction and analysis method

The AMPT model with string meting scenario [14], which has shown many good descriptions to some experimental observables [14–18], is implemented in this work. The AMPT model includes four main stages of high energy heavy-ion collisions:

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http://dx.doi.org/10.1016/j.physletb.2013.06.029

the initial condition, parton cascade, hadronization, and hadronic rescatterings. The initial condition, which includes the spatial and momentum distributions of minijet partons and soft string excitations, is obtained from HIJING model [19,20]. Next it starts the parton evolution with a quark and anti-quark plasma from the melting of strings. The scatterings among these quarks are treated by using the Zhang's Parton Cascade (ZPC) model [21] with the differential elastic scattering cross section

$$\frac{d\sigma}{dt} \approx \frac{9\pi\alpha_s^2}{2(t-\mu^2)^2}. \tag{1}$$

In the above, t is the standard Mandelstam variable for four momentum transfer, α_s is the strong coupling constant, and μ is the screening mass in the partonic matter. It recombines partons via a simple coalescence model to produce hadrons when the partons freeze out. Dynamics of the subsequent hadronic matter is then described by ART model [22]. In this work, the AMPT model with the newly fitted parameters for LHC energy [23] is used to simulate Pb + Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV. Two sets of partonic interaction cross sections, 0 and 1.5 mb, are applied to simulate two different physical scenarios for hadronic interactions only and parton + hadronic interactions, respectively.

In order to study the energy loss behaviors of γ-jet, a γ-jet of $p_T^\gamma \sim 60$ GeV/c with known initial production position and direction is triggered with the jet triggering technique in HIJING, since the production cross section of γ-jet is quite small especially for large transverse momentum. Three hard γ-jet production processes with high virtualities are additionally taken into account in the initial condition of the AMPT model, including $q+\bar{q} \to g+\gamma$, $q+\bar{q} \to \gamma+\gamma$ and $q+g \to q+\gamma$ [26]. For these prompt photons from γ-jet production, their birth information is kept for the analysis of γ-jet imbalance, since they only participate in electromagnetic interactions. On the other hand, the high-p_T primary partons pullulate to jet showers full of lower virtuality partons through initial- and final-state QCD radiations. In the string meting scenario of AMPT model, the jet parton showers are fragmented into hadrons with the LUND fragmentation, built in the PYTHIA routine [26], and then these hadrons are converted into on-shell quarks and anti-quarks according to the flavor and spin structures of their valence quarks. In a sense, the melting scenario for jets, which bears some analogy to the medium-induced subsequent radiations, but happens before jet-medium interactions in the logical structure of the AMPT model. After the melting process, not only a quark and anti-quark plasma is formed, but also jet quark shower is built up, therefore the initial configuration between γ-jet and the medium is ready to interact. In the following, the ZPC model automatically simulates all possible elastic partonic interactions among medium partons, between jet shower partons and medium partons, and among jet shower partons, but without the considerations of inelastic interactions or further radiations at present. Two sets of partonic interaction cross sections, 0 or 1.5 mb, are used to turn off or on the process of parton cascade in this study. When the partons freeze out, they are recombined into medium hadrons and jet shower hadrons via a simple coalescence model by combining the nearest partons into mesons and baryons. The final-state hadronic rescatterings including the interactions between jet shower hadrons and hadronic medium can be described by ART model [22].

The kinetic cuts for the analysis on γ-jet transverse momentum imbalance are chosen as CMS experiment did [10]. The transverse momentum of photon is required to be larger than 60 GeV/c ($p_T^\gamma > 60$ GeV/c) and its pseudorapidity is within a mid-rapidity gap of 1.44 ($|\eta^\gamma| < 1.44$). An anti-k_t algorithm from the standard Fastjet package is made use of to reconstruct the full jet [27].

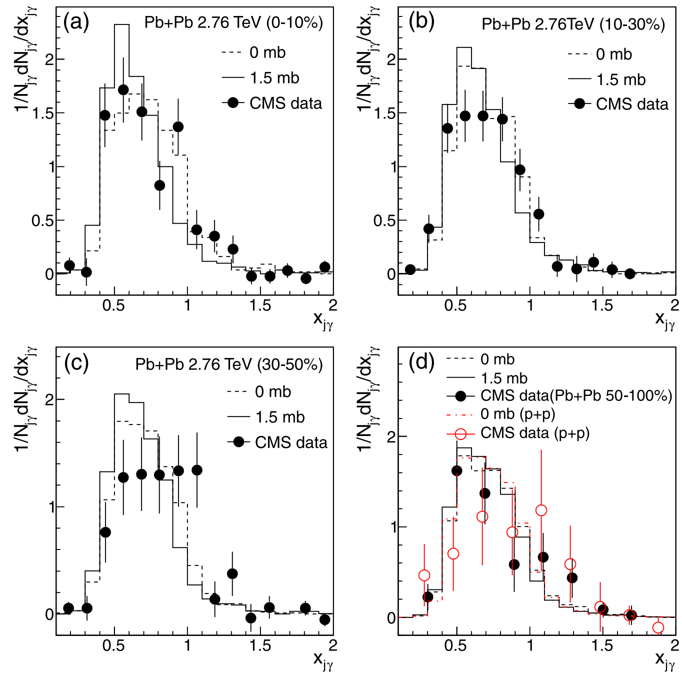

Fig. 1. (Color online.) The distributions of imbalance ratio $x_{j\gamma} = p_T^{jet}/p_T^\gamma$ between the photon ($p_T^\gamma > 60$ GeV/c) and jet ($p_T^{jet} > 30$ GeV/c, $\Delta\phi_{j\gamma} > 7\pi/8$) after background subtraction for four centrality bins in Pb + Pb and p + p collisions, where the solid (1.5 mb) and dash (0 mb) histograms represent the AMPT results with partonic + hadronic and hadronic interactions only respectively, while the circles represent the data from CMS experiment [10].

Jet cone size is set to be 0.3 ($R = 0.3$), p_T of jet is larger than 30 GeV/c ($p_T^{jet} > 30$ GeV/c) and pseudorapidity of jet is within a mid-rapidity range of $|\eta^{jet}| < 1.6$. A pseudorapidity strip of width $\Delta\eta = 1.0$ centered on the jet position, with two highest-energy jets excluded, is used to estimate the background ("average energy per jet area"), which is subtracted from the reconstructed jet energy in Pb + Pb collisions. Both jet energy scale and jet efficiency corrections, which are obtained by embedding triggered p + p into non-triggered Pb + Pb events, have been applied for each jet. The γ-jet-triggered events are weighted with the experimental measured prompt photon p_T spectra eventually [24,25].

3. γ-Jet transverse momentum imbalance

The transverse momentum imbalance is defined as the ratio of $x_{j\gamma} = p_T^{jet}/p_T^\gamma$ to study jet energy loss mechanism [10,11]. Fig. 1(a)–(d) show the imbalance ratio distributions for four centrality bins in Pb + Pb collisions and p + p collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV. The corresponding averaged values of imbalance ratio $\langle x_{j\gamma}\rangle$ as functions of number of participant nucleons N_{part} are presented in Fig. 2(a). The AMPT results with both partonic and hadronic interactions (i.e. 1.5 mb) give a little smaller $x_{j\gamma}$ and $\langle x_{j\gamma}\rangle$ than those with hadronic interactions only (i.e. 0 mb) and experimental data. On the other hand, Fig. 2(b) shows that only the AMPT result with both partonic and hadronic interactions can well reproduce the fraction $R_{j\gamma}$ of photons that have an associated jet with $p_T^{jet} > 30$ GeV/c. These results basically support the picture of jet quenching in partonic matter at LHC. To quantitatively learn how much jet loses its energy in partonic or hadronic matter, the averaged energy loss fractions of jet, $\langle\Delta p_T/p_T\rangle = \langle(p_T^{jet,initial} - p_T^{jet,final})/p_T^{jet,initial}\rangle$, are shown for the four centrality bins in Fig. 2(c). Jet loses its energy from by $\sim 15\%$ in central

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