

Tomography of QGP with jet asymmetries

Guo-Liang Ma

Shanghai Institute of Applied Physics, Chinese Academy of Sciences, P.O. Box 800-204,
Shanghai 201800, China

E-mail: glma@sinap.ac.cn

Abstract. Within a multi-phase transport (AMPT) model, the transverse momentum asymmetries for γ -jet and dijet are studied in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. A large asymmetry is produced by strong interactions between jets and partonic matter. It is demonstrated that hadronization and hadronic rescatterings have little effects on the formed asymmetries. The asymmetry evolution function discloses that final asymmetry is driven by both initial asymmetry and partonic jet energy loss. The γ -jet imbalance ratio, $x_{j\gamma}$, is sensitive to both production position and passing direction of γ -jet, which could enable a detail tomographic study on the formed partonic matter by selecting $x_{j\gamma}$.

1. Introduction

Jets, initially produced in hard scatterings, are thought as powerful probes to investigate the properties of the deconfined quark-gluon plasma (QGP), because they interact and loss energy when they pass the medium through in high-energy heavy-ion collisions [1]. Recently, the measurements based on full jet reconstruction further provide us a comprehensive understanding in jet energy loss mechanisms [2, 3, 4]. On the other hand, more information about the QGP medium is believed to be extracted with jet tomography, such as by using dijets or γ -jets [5, 6]. Compared to dijets, γ -jets have an innate advantage which makes γ -jets probe the QGP medium more deeply than dijets owing to photon's electromagnetic interactions only with the medium. In this work, both transverse momentum (p_T) asymmetries for reconstructed dijets and γ -jets are investigated within a multi-phase transport (AMPT) model for Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [7, 8]. With the help of their asymmetries, a detail γ -jet tomography is proposed to study different initial configurations between jets and the partonic matter.

2. Jet reconstruction in the AMPT model

The AMPT model with string melting scenario is implemented in this work [9]. It consists of four main stages of high-energy heavy-ion collisions: the initial condition, parton cascade, hadronization, and hadronic rescatterings. In order to study the transport behaviors of jets, a dijet ($p_T \sim 120$ GeV/ c) or a γ -jet ($p_T \sim 60$ GeV/ c) is triggered in the initial condition based on HIJING model. The high- p_T primary partons pullulate to jet showers full of lower virtuality partons through initial- and final- state QCD radiations. The jet parton showers are converted into clusters of on-shell quarks and anti-quarks through the string meting mechanism of AMPT model. After the melting process, both a quark and anti-quark plasma and jet quark showers are built up. In the following, Zhang's parton cascade (ZPC) model automatically simulates all possible elastic partonic interactions among medium partons and jet shower partons, but without

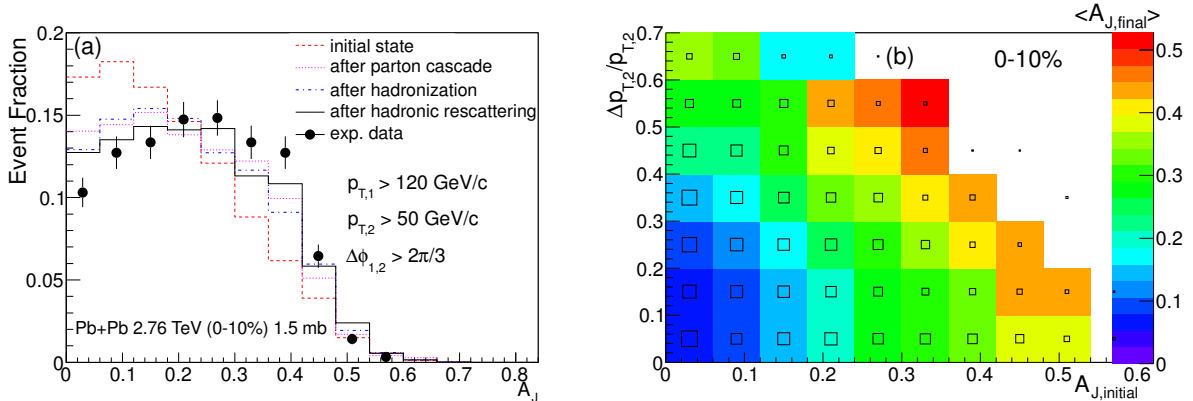


Figure 1. The AMPT results on the dijet asymmetry ratio A_J distributions at different evolution stages (a) and the dijet A_J evolution function $[\langle A_{J,final} \rangle(A_{J,initial}, \Delta p_{T,2}/p_{T,2})]$ (b) for most central Pb+Pb collisions.

including inelastic parton interactions or further radiations at present. When the partons freeze out, they are recombined into medium hadrons or jet shower hadrons via a simple coalescence model. The final-state hadronic interactions between jet shower hadrons and hadronic medium then are described by a relativistic transport (ART) model.

An anti- k_t algorithm from the standard Fastjet package is used to reconstruct jets [10]. The kinetic cuts are chosen as in the CMS experiments [3, 4]. The jet cone size (R) is set to be 0.5 or 0.3 for dijet or γ -jet study, respectively. 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, which is subtracted from the reconstructed jet energy in Pb+Pb collisions.

3. Results and discussions

To describe dijet p_T asymmetry, an asymmetry ratio is defined as $A_J=(p_{T,1} - p_{T,2})/(p_{T,1} + p_{T,2})$ as LHC experiments did [2, 3]. Since heavy-ion collisions are dynamical evolutions including many important stages, Figure 1 (a) compares the A_J distributions at or after different evolution stages with experimental data in most central Pb+Pb collisions (0-10%) at $\sqrt{s_{NN}} = 2.76$ TeV. The dijet asymmetry ratio A_J increases from “initial state” to “after parton cascade” because jets, especially for subleading jets, lose much energy when they pass through the partonic matter. However, the following hadronization and hadronic rescattering processes do not seem to affect the formed A_J distribution any more.

To study how the initial A_J evolves into the final A_J , an asymmetry evolution function is defined as $\langle A_{J,final} \rangle(A_{J,initial}, \Delta p_{T,2}/p_{T,2})$, which neglects the leading jet energy loss. Figure 1 (b) shows the dijet A_J evolution functions for most central Pb+Pb collisions (0-10%) at $\sqrt{s_{NN}} = 2.76$ TeV, where the color of cell denotes the $\langle A_{J,final} \rangle$ and the size of box in each cell represents the possibility of dijet events. It is found that final A_J of dijet events is driven by two sources. The first one is the remaining A_J part for which dijets keep their initial A_J with small jet energy loss fractions. The second one is the newly formed A_J part for which jets lose much more energy to increase their original A_J , which actually is the dominant source for the observed enhancement of large dijet asymmetry in the central collisions.

The γ -jet p_T imbalance is defined as the ratio of $x_{j\gamma}=p_T^{jet}/p_T^\gamma$ to study γ -jet energy loss mechanism [4]. Figure 2 (a) gives the distributions of imbalance ratio $x_{j\gamma}$ at or after different evolution stages for most central Pb+Pb collisions (0-10%) at $\sqrt{s_{NN}} = 2.76$ TeV. Similarly as the formation of dijet asymmetry, γ -triggered jets mainly lose their energy in the parton

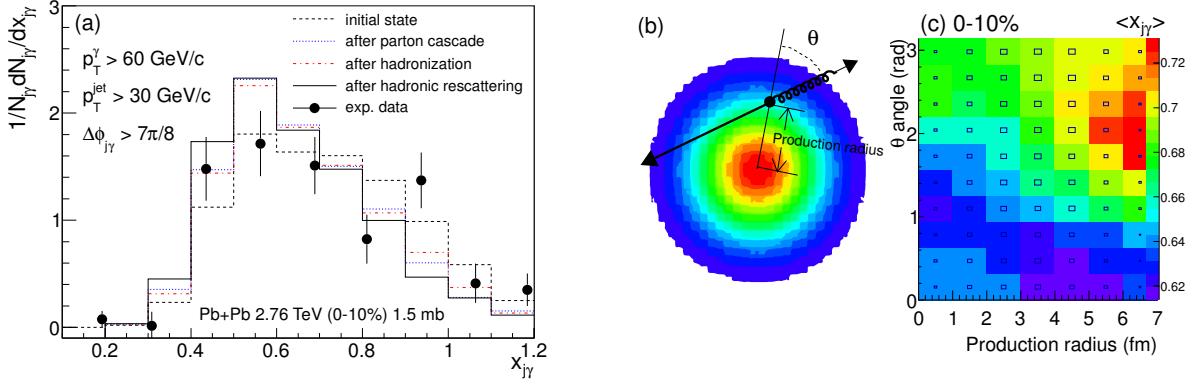


Figure 2. (a) The imbalance ratio $x_{j\gamma}$ distributions at different evolution stages for most central Pb+Pb collisions. (b) Illustration of the production of γ -jet which passes through the partonic medium in a central Pb+Pb collision. (c) The production radius and direction dependences of averaged imbalance ratio, $\langle x_{j\gamma} \rangle(r, \theta)$ for most central Pb+Pb collisions.

cascade process. Therefore, the γ -jet measurements can basically reflect the information about the interactions between jets and partonic matter.

However, the current measurements are the inclusive results from the average of all cases for γ -jets with any possible production position and direction. As Figure 2 (b) illustrates, a pair of photon and jet can be produced at a position (the black dot), where is at a distance of production radius r to the center, in a central Pb+Pb collision. The direction of photon can be represented by a θ angle which is the angle between the passing direction of photon and the vector from the center to production point. Figure 2 (c) shows the production radius and direction dependence of imbalance ratio of γ -jets, i.e. the averaged value $\langle x_{j\gamma} \rangle$ at (r, θ) , for most central Pb+Pb collisions (0-10%) at $\sqrt{s_{\text{NN}}} = 2.76$ TeV, where the color of cell denotes the $\langle x_{j\gamma} \rangle$ and the size of box in cell represents the possibility for γ -jet events with r and θ . The present measurements actually include all initial configurations of (r, θ) between γ -jets and the medium. They basically can be divided into three typical cases. (I) Punch-through jet cases with large radii and small θ angles, corresponding to small $x_{j\gamma}$ values. (II) Escaped-jet cases with large radii and large θ angles, corresponding to large $x_{j\gamma}$. (III) Tangential-jet cases with large radii and θ angles $\sim \pi/2$, corresponding to middle $x_{j\gamma}$. The two-dimensional dependence of $\langle x_{j\gamma} \rangle(r, \theta)$ in Figure 2 (c) indicates that final $x_{j\gamma}$ is sensitive to the initial γ -jet production information to a certain degree.

Based on the dependence of $\langle x_{j\gamma} \rangle(r, \theta)$, the different initial γ -jet production configurations could be classified by selecting $x_{j\gamma}$ range. For instance, Figure 3 (a)-(d) show the possibility distributions of measured γ -jet events in r - θ plane with different $x_{j\gamma}$ range selections. Figure 3 (e) shows the hadron azimuthal correlation associated with a triggered γ under the different $x_{j\gamma}$ selections, where the more enhanced away-side peak is observed with the decreasing of $x_{j\gamma}$. The inserted plot of Figure 3 (e) displays the corresponding ratios of γ -hadron correlations for away-side between central Pb+Pb and p+p collisions for different $x_{j\gamma}$ selections. It is pronounced to observe the large enhancement of two side peaks in small $x_{j\gamma}$ classes of Pb+Pb events, which indicates the deflection of both Mach-cone like medium excitation and jet shower by radial flow [11] are more likely formed for the punch-through configurations of γ -jet in central Pb+Pb collisions. Therefore, it provides an effective way to zoom in the medium responses by using γ -hadron correlations associated with different $x_{j\gamma}$ selections.

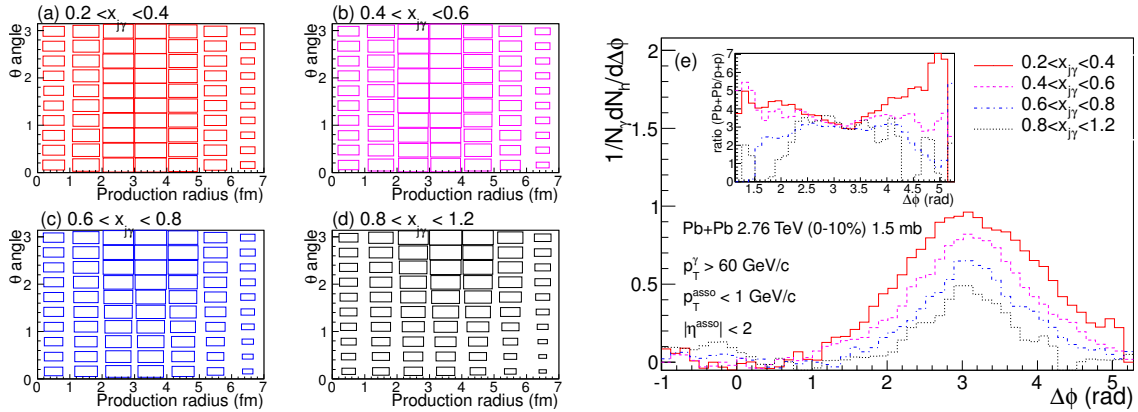


Figure 3. (a)-(d) The possibility distributions of measured γ -jet events in r - θ plane with different $x_{j\gamma}$ selections for most central Pb+Pb collisions. (e) The γ -hadron azimuthal correlations for the most central Pb+Pb collisions with different $x_{j\gamma}$ ranges, where the inserted panel shows the corresponding away-side γ -hadron correlation ratios of most central Pb+Pb to p+p collisions.

4. Summary

In summary, the p_T asymmetries for dijets and γ -jets are investigated with a multi-phase transport model for Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. A large asymmetry is produced by strong interactions between jets and partonic matter, and hardly affected by hadronization and hadronic rescatterings. The final asymmetry is basically driven by both initial asymmetry and partonic jet energy loss. The imbalance ratio, $x_{j\gamma}$, is sensitive to both production position and passing direction of γ -jet, which could enable a detail tomographic study on the formed partonic matter.

Acknowledgments

This work was supported by the Major State Basic Research Development Program in China under Contract No. 2014CB845404; the NSFC of China under Projects No. 11175232, No. 11035009, and No. 11375251; the Knowledge Innovation Program of CAS under Grant No. KJCX2-EW-N01; the Youth Innovation Promotion Association of CAS; and the project sponsored by SRF for ROCS, SEM; CCNU-QLPL Innovation Fund (Grant No. QLPL2011P01); the "Shanghai Pujiang Program" under Grant No. 13PJ1410600.

References

- [1] Wang X N and Gyulassy M, 1992 Phys. Rev. Lett. **68**, 1480
- [2] Aad G *et al.* (ATLAS Collaboration), 2010 Phys. Rev. Lett. **105**, 252303
- [3] Chatrchyan S *et al.* (CMS Collaboration), 2011 Phys. Rev. C **84**, 024906
- [4] Chatrchyan S *et al.* (CMS Collaboration), 2013 Phys. Lett. B **718**, 773
- [5] Zhang H, Owens J F, Wang E and Wang X N, 2017 Phys. Rev. Lett. **98**, 212301
- [6] Zhang H, Owens J F, Wang E and Wang X N, 2009 Phys. Rev. Lett. **103**, 032302
- [7] Ma G L, 2013 Phys. Rev. C **87**, 064901
- [8] Ma G L, 2013 Phys. Lett. B **724**, 278
- [9] Lin Z W, Ko C M, Li B A, Zhang B and Pal S, 2005 Phys. Rev. C **72**, 064901
- [10] Cacciari M, Salam G P and Soyez G, 2012 Eur. Phys. J. C **72**, 1896
- [11] Li H, Liu F, Ma G L, Wang X N and Zhu Y, 2011 Phys. Rev. Lett. **106**, 012301